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Abstract

This document describes how to model TE topologies and tunnels for transport networks, by using the TE topology YANG model [I-D.ietf-teas-yang-te-topo] and the TE tunnel YANG model [I-D.ietf-teas-yang-tel].

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

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1. Modeling Considerations

1.1. TE Topology Model

The TE Topology Model is written in YANG modeling language. It is defined and developed by the IETF TEAS WG and is documented as "YANG Data Model for TE Topologies" [I-D.ietf-teas-yang-te-topo]. The model describes a TE network provider's Traffic Engineering data store as it is seen by a client. It allows for the provider to convey to each of its clients:

- o information on network resources available to the client in the form of one or several native TE topologies (for example, one for each layer network supported by the provider);
- o one or several abstract TE topologies, customized on per-client basis and sorted according to the provider's preference as to how the abstract TE topologies are to be used by the client;
- o updates with incremental changes happened to the previously provided abstract/native TE topology elements;

- o updates on telemetry/state information the client has expressed interest in;
- o overlay/underlay relationships between the TE topologies provided to the client (e.g. TE path computed in an underlay TE topology supporting a TE link in an overlay TE topology);
- o client/server inter-layer adaptation relationships between the TE topologies provided to the client in the form of TE inter-layer locks or transitional links;

The TE Topology Model allows a network client to:

- o (Re-)configure/negotiate abstract TE topologies provided to the client by a TE network provider, so that said abstract TE topologies optimally satisfy the client's needs, constraints and optimization criteria, based on the client's network planning, service forecasts, telemetry information extracted from the network, previous history of service provisioning and performance monitoring, etc.;
- o Obtain abstract/native TE topologies from multiple providers and lock them horizontally (inter-domain) and vertically (inter-layer) into the client's own native TE topologies;
- o Configure, with each provider the trigger, frequency and contents of the TE topology update notifications;
- o Configure, with each provider the trigger, frequency and contents of the TE topology telemetry (e.g. statistics counters) update notifications.

1.2. TE Topology Modeling Constructs

Figure 1. TE Topology

- o TE domain - a multi-layer traffic engineered network under direct and complete control of a single authority, network provider. TE domain can be described by one or more TE topologies. For example, separate TE topologies can describe each of the domain's layer networks. TE domain can hierarchically encompass/parent other (child) TE domains, and can be encompassed by its own parent.
- o TE topology - a graphical representation of a TE domain. TE topology is comprised of TE nodes (TE graph vertices) interconnected via TE links (TE graph edges).

```

/* TE topology */
augment /nw:networks/nw:network:
  /* TE topology global ID */
  +--rw provider-id?      te-types:te-global-id
  +--rw client-id?       te-types:te-global-id
  +--rw te-topology-id?   te-types:te-topology-id
  .....
  /* TE topology general parameters */
  |   +--rw preference?          uint8
  |   +--rw optimization-criterion? identityref
  .....

```

```
        /* TE topology list of TE nodes */
augment /nw:networks/nw:network/nw:node:
  +--rw te-node-id?   te-types:te-node-id
.....
        /* TE topology list of TE links */
augment /nw:networks/nw:network/nt:link:
.....
        /* TE topology list of TE link termination points */
augment /nw:networks/nw:network/nw:node/nt:termination-point:
  +--rw te-tp-id?   te-types:te-tp-id
.....
```

Figure 2. TE Node

- o TE node - an element of a TE topology (appears as a vertex on TE graph). A TE node represents one or several nodes (physical switches), or a fraction of a node. A TE node belongs to and is fully defined in exactly one TE topology. A TE node is assigned a TE topology scope-unique ID. TE node attributes include information related to the data plane aspects of the associated node(s) (e.g. TE node's connectivity matrix), as well as configuration data (such as TE node name). A given TE node can be reached on the TE graph, representing the TE topology, over one of TE links terminated by the TE node.

```

/* TE node */
augment /nw:networks/nw:network/nw:node:
  /* TE node ID */
  +--rw te-node-id?   te-types:te-node-id
  .....
  /* TE node general attributes */
  |   +--rw te-node-attributes */
  .....
  /* TE node connectivity matrices */
  |   +--rw connectivity-matrices
  .....
  /* TE node underlay TE topology */
  |   +--rw underlay-topology {te-topology-hierarchy}?
  |   +--rw network-ref?   leafref
  .....
  /* TE node information sources*/
  |   +--ro information-source-entry* [information-source]
  .....
  /* TE node statistics */
  +--ro statistics
  .....
  /* TE node TTP list */
  +--rw tunnel-termination-point* [tunnel-tp-id]
  .....

```

```

/* TE link */
augment /nw:networks/nw:network/nt:link:
/* TE link bundle information */
|   +--rw (bundle-stack-level)?
|   |   +--rw bundled-links
|   |   +--rw component-links
|
.....
/* TE link general attributes */
|   +--rw te-link-attributes
|
.....
/* TE link underlay TE topology */
|   +--rw underlay! {te-topology-hierarchy}?
|   |   +--rw primary-path
|   |   +--rw backup-path* [index]
|
.....
/* TE link layer network */
|   +--rw interface-switching-capability* [switching-
capability encoding]
|
.....
/* TE link protection type */
|   |   +--rw protection-type?    uint16
|
.....

/* TE link supporting TE tunnels */
|   +--rw tunnels

```



```

.....
/* TE link transitional link flag */
|   +--ro is-transitional?           empty

.....
/* TE link information sources */
|   +--ro information-source?       te-info-source

.....
/* TE link statistics */
+--ro statistics

.....

```

- o Intra-domain TE link - TE link connecting two TE nodes within the same TE topology representing a TE network domain (e.g. L14 in Figure 1). From the point of view of the TE topology where the intra-domain TE link is defined, the TE link is close-ended, that is, both local and remote TE nodes of the link are defined in the same TE topology.
- o Inter-domain TE link - TE link connecting two border TE nodes that belong to separate TE topologies describing neighboring TE network domains (e.g. L3x in Figure 1). From the point of view of the TE topology where the inter-domain TE link is defined, the TE link is open-ended, that is, the remote TE node of the link is not defined in the TE topology where the local TE node and the TE link itself are defined.

[Note: from the point of view of a TE node terminating an inter-domain TE link there is no difference between inter-domain and access TE links]

- o Access TE link - TE link connecting a border TE node of a TE topology describing a TE network domain to a TE node of a TE topology describing a customer network site (e.g. L1x in Figure 1). From the point of view of the TE topology where the access TE link is defined, the TE link is open-ended, that is, the remote TE node of the link (t.e. TE node representing customer network element(s)) is not defined in the TE topology where the local TE node and the TE link itself are defined.

[Note: from the point of view of a TE node terminating an access TE link there is no difference between access and inter-domain TE links]

- o Dynamic TE link - a TE link that shows up in (and disappears from) a TE topology as a result of multi-layer traffic engineering. Dynamic TE link (supported by a hierarchy TE tunnel dynamically set up in a server layer network) is automatically (i.e. without explicit configuration request) added to a client layer network TE topology to augment the topology with additional flexibility to ensure successful completion of the path computation for and provisioning of a client layer network connection/LSP. For example, an ODUk hierarchy TE tunnel can support a dynamic Ethernet layer TE link to enable provisioning of an Ethernet layer connection on a network that does not have sufficient static Ethernet layer connectivity. Likewise, dynamic TE link is automatically removed from the TE topology (and its supporting hierarchy TE tunnel released) as soon as the TE link stops carrying client layer connections/LSPs.
- o TE link termination point (LTP) - a conceptual point of connection of a TE node to one of the TE links terminated by the TE node (see Figure 2a). Unlike TE link, LTP is bi-directional - an inbound TE link and an oppositely directed outbound TE link have to be connected to the TE node via the same LTP to constitute a bi-directional TE link combination.

Figure 2a. Bi-directional TE link combination (left), independent uni-directional TE links (right)

```

/* LTP */
augment /nw:networks/nw:network/nw:node/nt:termination-point:
/* LTP ID */
  +--rw te-tp-id?    te-types:te-tp-id
/* LTP network layer ID */
  | +--rw interface-switching-capability* [switching-
capability encoding]
  | | +--rw switching-capability    identityref

```

```

    | |  +--rw encoding                identityref
/* LTP bandwidth information */
    | |  +--rw max-lsp-bandwidth* [priority]
    | |      +--rw priority            uint8
    | |      +--rw bandwidth?         te-bandwidth
/* LTP inter-layer locks */
    |  +--rw inter-layer-lock-id?      uint32
.....

```

- o TE tunnel termination point (TTP) - an element of TE topology representing one or several potential TE tunnel termination/adaptation points (e.g. OCh layer transponder). A TTP is hosted by exactly one TE node (see Figure 2). A TTP is assigned a TE node scope-unique ID. Depending on the TE node's internal constraints, a given TTP hosted by the TE node could be accessed via one, several or all TE links originated/terminated from/by the TE node. TTP's important attributes include Local Link Connectivity List, Adaptation Client Layer List, TE inter-layer locks (see below), Unreserved Adaptation Bandwidth (announcing the TTP's remaining adaptation resources sharable between all potential client LTPs), and Property Flags (indicating miscellaneous properties of the TTP, such as capability to support 1+1 protection for a TE tunnel terminated on the TTP).

```

/* TTP */
    +--rw tunnel-termination-point* [tunnel-tp-id]
/* TTP ID */
    +--rw tunnel-tp-id                                binary
/* TTP layer network ID */
    |  +--rw switching-capability?                    identityref
    |  +--rw encoding?                                identityref
/* Inter-layer-locks supported by TTP */
    |  +--rw inter-layer-lock-id?                      uint32
/* TTP's protection capabilities */
    |  +--rw protection-type?                          identityref
/* TTP's list of client layer users */
    |  +--rw client-layer-adaptation
.....
/* TTP's Local Link Connectivity List (LLCL) */

```

```
|  +-rw local-link-connectivities
.....

```

o Label - in the context of circuit switched layer networks identifies a particular resource on a TE link (e.g. Och wavelength, ODUk container)

```
+-:-(label)
  +-rw value?   rt-types:generalized-label
```

Figure 3. TTP Local Link Connectivity List

- o TTP basic local link connectivity list (basic LLCL) - a list of TE link/label combinations terminated by the TTP-hosting TE node (effectively the same as LTP/label pairs), which the TTP could be connected to (see Figure 3, upper left). From the point of view of a potential TE path, basic LLCL provides a list of permissible LTP/label pairs the TE path needs to start/stop on for a connection, taking the TE path, to be successfully terminated on the TTP in question.
- o TTP detailed local link connectivity list (detailed LLCL) - basic LLCL extended to provide a set of costs (such as intra-node summary TE metric, delay, SRLGs, etc.) associated with each LLCL entry (see Figure 3, upper right)

```

/* TTP LLCL */
|  +--rw local-link-connectivities
|      |  +--rw number-of-entries?          uint16
|      /* LLCL entry */
|
|      /* LLCL entry LTP */
|      |  +--rw link-tp-ref                  leafref
|
.....

/* LLC entry label range */
|      +--rw label-restriction* [inclusive-exclusive label-start]
|      |  +--rw inclusive-exclusive          enumeration
|      |  +--rw label-start                  rt-types:generalized-label
|      |  |  +--rw label-end?                rt-types:generalized-
label
|      |  |  +--rw range-bitmap?              binary
|
.....

/* LLCL entry underlay TE path(s) */
|      +--rw underlay! {te-topology-hierarchy}?
|      |  +--rw primary-path
|      |  +--rw backup-path* [index]
/* LLCL entry protection type */
|      |  +--rw protection-type?            uint16
/* LLCL entry supporting TE tunnels */
|      |  +--rw tunnels
/* LLCL entry bandwidth parameters */
|      |  +--rw max-lsp-bandwidth* [priority]
|
.....

```

```

/* LLCL entry metrics (vector of costs) */
|   +--rw te-default-metric?          uint32
|   +--rw te-delay-metric?            uint32
|   +--rw te-srlgs
|   |   +--rw value*      te-types:srlg
|   +--rw te-nsrlgs {nsrlg}?

```

```

.....
/* LLCL entry ID */
|   |   +--rw id*      uint32

```

- o TTP adaptation client layer list - a list of client layers that could be directly adopted by the TTP. This list is necessary to describe complex multi-layer (more than two layer) client-server layer hierarchies and, in particular, to identify the position of the TTP in said hierarchies.

```

/* TTP adaptation client layer list */
|   +--rw client-layer-adaptation
|   |   +--rw switching-capability* [switching-capability
encoding]
|   |   /* Client layer ID */
|   |   |   +--rw switching-capability      identityref
|   |   |   +--rw encoding                  identityref
|   |   /* Adaptation bandwidth available for the client layer */
|   |   +--rw bandwidth?                    te-bandwidth

```

Figure 4. TE Node Connectivity Matrix

- o TE node basic connectivity matrix - a TE node attribute describing the TE node's switching capabilities/limitations in the form of permissible switching combinations of the TE node's LTP/label pairs (see Figure 4, upper left). From the point of view of a potential TE path arriving at the TE node at a given inbound LTP/label, the node's basic connectivity matrix describes permissible outbound LTP/label pairs for the TE path to leave the TE node.
- o TE node detailed connectivity matrix - TE node basic connectivity matrix extended to provide a set of costs (such as intra-node summary TE metric, delay, SRLGs, etc.) associated with each connectivity matrix entry (see Figure 4, upper right).

```

/* TE node connectivity matrix */
    |--rw connectivity-matrix* [id]
    |--rw id                               uint32
    |--rw from /* left LTP */

```

```

|         |  +--rw tp-ref?    leafref
|         |  +--rw to        /* right LTP */
|         |  +--rw tp-ref?    leafref
|         |  +--rw is-allowed?                boolean

/* Connectivity matrix entry label range */
|         |  +--rw label-restriction* [inclusive-exclusive
label-start]
|         |  +--rw inclusive-exclusive        enumeration
|         |  +--rw label-start                rt-
types:generalized-label
|         |  +--rw label-end?                rt-
types:generalized-label
|         |  +--rw range-bitmap?              binary

/* Connectivity matrix entry underlay TE path(s) */
|         |  +--rw underlay! {te-topology-hierarchy}?
|         |  +--rw primary-path
|         |  +--rw backup-path* [index]
/* Connectivity matrix entry protection type */
|         |  +--rw protection-type?    uint16
/* Connectivity matrix entry supporting TE tunnels */
|         |  +--rw tunnels
/* Connectivity matrix entry bandwidth parameters */
|         |  +--rw max-lsp-bandwidth* [priority]

.....
/* Connectivity matrix entry metrics (vector of costs) */
|         |  +--rw te-default-metric?    uint32
|         |  +--rw te-delay-metric?      uint32
|         |  +--rw te-srlgs
|         |  |  +--rw value*    te-types:srlg
|         |  +--rw te-nsrlgs {nsrlg}?

.....
/* Connectivity matrix entry ID */
|         |  +--rw id*    uint32

```

Figure 5. TE Path

- o TE path - an ordered list of TE node/link IDs (each possibly augmented with labels) that interconnects over a TE topology a pair of TTPs and could be used by a connection (see Figure 5). A TE path could, for example, be a product of a successful path computation performed for a given TE tunnel

```

/* TE path */

/* TE topology the path is defined in */
| | | +--rw network-ref?    leafref
/* Path type (IRO, XRO, ERO, RRO) */
| | | +--rw path-type?     identityref

/* TE path elements */
| | | +--rw path-element* [path-element-id]
| | | |   +--rw path-element-id    uint32
| | | |   +--rw index?             uint32
| | | |   +--rw (type)?
/* Numbered TE link path element */
| | | |   +--:(ip-address)
| | | | |   +--rw ip-address-hop
| | | | |   +--rw address?         inet:ip-address

```

```
| | | +---rw hop-type?      te-hop-type  
| | | /* AS number path element */  
| | |     +---:(as-number)  
| | |         +---rw as-number-hop  
| | |             +---rw as-number?      binary  
| | |                 +---rw hop-type?    te-hop-type  
| | | /* Unnumbered TE link path element */  
| | |     +---:(unnumbered-link)  
| | |         +---rw unnumbered-hop  
| | |             +---rw te-node-id?      inet:ip-address  
| | |                 +---rw tp-id?       uint32  
| | |                     +---rw hop-type?    te-hop-type  
| | | /* Label path element */  
| | |     +---:(label)  
| | |         +---rw label-hop  
| | |             +---rw value?          rt-types:generalized-label  
| | |                 +---rw direction?    boolean  
| | |     +---:(sid)  
| | |         +---rw sid-hop  
| | |             +---rw sid?            rt-types:generalized-label
```

- o TE path segment - a contiguous fragment of a TE path

Figure 6. TE Inter-Layer Lock

- o TE inter-layer lock - a modeling concept describing client-server layer adaptation relationships important for multi-layer traffic engineering. It is an association of M client layer LTPs and N server layer TTPs, within which data arriving at any of the client layer LTPs could be adopted onto any of the server layer TTPs. A TE inter-layer lock is identified by inter-layer lock ID, which is unique across all TE topologies provided by the same provider. The client layer LTPs and the server layer TTPs associated by a given TE inter-layer lock share the same inter-layer lock ID value.

In Figure 6 a TE inter-layer lock IL_1 associates six client layer LTPs (C_LTP_1 - C_LTP_6) with two server layer TTPs (S_TTP_1 and S_TTP_2). As mentioned, they all have the same attribute -inter-layer lock ID: IL_1, which is the only parameter/value indicating the association. A given LTP may have zero, one or more inter-layer lock IDs. In the case of multiple inter-layer lock IDs, this implies that the data arriving at the LTP can be adopted onto any of TTPs associated with all specified inter-layer locks. For example, C_LTP_1 may be attributed with two inter-layer locks- IL_1 and IL_2. This would mean that C_LTP_1 for adaptation purposes can use not just TTPs associated with inter-layer lock IL_1 (i.e. S_TTP_1 and S_TTP_2 in the Figure), but any of TTPs associated with inter-layer lock IL_2. Likewise, a given TTP may have one or more inter-layer locks, meaning that it can offer the adaptation service to any client layer LTP having an inter-layer lock matching one of its own.

LTPs and TTPs associated within the same TE inter-layer lock may be hosted by the same (hybrid, multi-layer) TE node or by multiple TE nodes defined in the same or separate TE topologies. The latter case is especially important because TE topologies of different layer networks could be modeled by separate augmentations of the basic (common to all layers) TE topology model.

```
|  +--rw inter-layer-lock-id?          uint32
```

- o Transitional link - an alternative method of modeling of client-server adaptation relationship. Transitional link is a bi-directional link connecting an LTP in a client layer to an LTP in a server layer, which is associated (via TTP's LLCL) with a server layer TTP capable of adopting of the client layer data onto a TE tunnel terminated by the TTP. Important attributes of a transitional link are local/remote LTP IDs, TE metric and available adaptation bandwidth.

Figure 7. Native and Abstract TE Topologies

- o Native TE topology - a TE topology as it is known (to full extent and unmodified) to the TE topology provider (see lower part of Figure 7.). A native TE topology might be discovered via various routing protocols and/or subscribe/publish techniques. For example, a first-level TE topology provider (such as a T-SDN Domain Controller, DC) may auto-discover its native TE topology(ies) by participating in the domain's OSPF-TE protocol instance; while a second-level TE topology provider (such as a Hierarchical T-SDN Controller, HC) normally builds its native TE topology(ies) based on TE topologies exposed by each of the subordinate, first-level TE topology providers.
- o Underlay TE topology - a TE topology that serves as a base for constructing overlay TE topologies.

- o Overlay TE topology - a TE topology constructed based on one or more underlay TE topologies. Each TE node of the overlay TE topology represents a separate underlay TE topology (that could be mapped onto an arbitrary segment of a native TE topology). Each TE link of the overlay TE topology represents, generally speaking, an arbitrary TE path in one of the underlay TE topologies. The overlay TE topology and the supporting underlay TE topologies may represent separate layer networks (e.g. OTN/ODUk and WDM/OCh respectively) or the same layer network.
- o Abstract TE topology - an overlay TE topology created by a provider to describe its network in some abstract way. An abstract TE topology contains at least one abstract TE topology element, such as TE node or TE link. An abstract TE topology is built based on contents of one or more of the provider's native TE topologies (serving as underlay(s)), the provider's policies and the client's preferences (see upper part of Figure 7).
- o Customized TE topology - a TE topology tailored for a given provider's client. A customized TE topology is usually but not always an abstract TE topology. For example, a given abstract TE topology could be exposed to a group or all provider's clients (in which case the abstract TE topology is not a customized TE topology). Likewise, a given naive TE topology could be customized for a given client (for example, by removing high delay TE links the client does not care about). So customized TE topology is not an abstract TE topology, because it does not contain abstract TE topology elements
- o TE inter-domain plug - a TE link attribute meaningful for open-ended inter-domain/access TE links. It contains a network-wide unique value (inter-domain plug ID) that identifies in the network a connectivity supporting the inter-domain/access TE link in question. It is expected that a given pair of neighboring domain TE topologies (provided by separate providers) will have each at least one open-ended inter-domain/access TE link with a TE inter-domain plug matching to one provided by its neighbor, thus allowing for a client of both domains to identify adjacent nodes in the separate neighboring TE topologies and resolve the open-ended inter-domain/access TE links by connecting them regardless of the links respective local/remote node ID/link ID attributes. Inter-domain plug IDs may be assigned and managed by a central network authority. Alternatively, inter-domain plug IDs could be dynamically auto-discovered (e.g. via LMP protocol).

```

+--rw external-domain
|   +--rw network-ref?          leafref
|   +--rw remote-te-node-id?    te-types:te-node-id
|   +--rw remote-te-link-tp-id? te-types:te-tp-id
|   +--rw plug-id?              uint32

```

1.3. Abstract TE Topology Calculation, Configuration and Maintenance

The TE Topology Model does not prescribe what and how abstract TE topologies are computed, configured, manipulated and supported by a TE network (e.g. transport network) provider. However, it is assumed that:

- o All TE topologies, native or abstract, conveyed to the same or different clients, are largely independent one from another. This implies that each TE topology, generally speaking, has an independent name space for TE node and link IDs, SRLGs, etc. (possibly overlapping with the name spaces of other TE topologies);
- o All abstract TE topologies are bound to the respective underlay native or abstract TE topologies only by the overlay/underlay relationships defined by the TE Topology Model, but, otherwise, the abstract TE topologies are decoupled from their respective underlay TE topologies.

It is envisioned that an original set of abstract TE topologies is produced by a TE network provider for each of its clients based on the provider's local configurations and/or policies, as well as the client-specific profiles. The original set of abstract TE topologies offered to a client may be accepted by the client as-is. Alternatively, the client may choose to negotiate/re-configure the abstract TE topologies, so that the latter optimally satisfy the client's needs. In particular, for each of the abstract TE topologies the client may request adding/removing TE nodes, TE links, TTPs and/or modifying re-configurable parameters of the existing components. The client may also request different optimization criteria as compared to those used for the original abstract TE topology optimization, or/and specify various topology-level constraints. The provider may accept or reject all or some abstract TE topology re-configuration requests. Hence, the abstract TE topology negotiation process may take multiple iterations before the provider and each of its clients agree upon a set of abstract TE

topologies and their contents. Furthermore, the negotiation process could be repeated over time to produce new abstract TE topologies optimal to best suit evolving circumstances.

Figure 8. Native Transport Network Domain TE Topology as an Underlay for Abstract TE Topologies

Let's assume that a native transport network domain TE topology to be as depicted in Figure 8. The popular types of abstract TE topologies based on this native TE topology as an underlay are described in the following sections.

1.3.1. Single-Node Abstract TE Topology

Figure 9. Blocking/Asymmetrical TE Node with Basic Connectivity Matrix Attribute

In Figure 9, the transport network domain is presented to a client as a one-node abstract TE topology, where the single TE node (AN1) represents the entire domain and terminates all of the inter-domain/access TE links connecting the domain to its adjacent domains (i.e. TE links L1...L8). Because AN1 represents the entire domain the node's Underlay TE Topology attribute matches the ID of one of the domain's native TE topologies (e.g. one presented in Figure 8). [Note: all or some of the underlay TE topologies a given abstract TE topology depends on could be catered to the client by the provider along with the abstract TE topology in question or upon separate request(s) issued by the client.]

One important caveat about abstract TE node AN1 is that it should be considered as an asymmetrical/blocking switch, because, generally speaking, it is not guaranteed that a suitable TE path exists between any given pair of inter-domain TE links into/out of the domain. This means from the TE Topology model point of view that there are certain limitations as to how AN1's LTPs could be interconnected inside/across the TE node. The model allows for asymmetrical/blocking switches by specifying for the associated TE nodes a non-empty basic connectivity matrix attribute describing permissible inbound-outbound TE link/label switching combinations. It is assumed that the provider's path computer can compute a set of optimal TE paths, connecting inbound TE link/label_x <=> outbound TE link/label_y combinations inside the abstract TE node over the TE node's underlay TE topology. Based on the results of such computations, AN1's

connectivity matrix can be (re-)generated and (re-)conveyed to the abstract TE topology client.

A richer version of the basic connectivity matrix is the detailed connectivity matrix. The latter not only describes permissible inbound TE link/label_x <=> TE link/label TE link/label_y switching combinations, but also provides connectivity matrix entry specific vectors of various costs/metrics (in terms of delay, bandwidth, intra-node SRLGs and summary TE metrics) that a potential TE path will accrue, should a given connectivity matrix entry be selected by the path for crossing the TE node (see Figure 10).

Figure 10. Blocking/Asymmetrical TE Node with Detailed Connectivity Matrix Attribute

1.3.2. Full Mesh Link Abstract TE Topology

Figure 11. Full Mesh Link Abstract TE Topology

In Figure 11, the transport network domain is abstracted in the following way.

- o Each of the underlay native TE topology border TE nodes (i.e., the TE nodes terminating at least one inter-domain/access TE link, such as TE nodes S3 or S11 in Figure 8) is represented in the abstract TE topology as a separate abstract TE node, matching one-for-one to the respective border TE node of the underlay TE topology. For example, S3' of the abstract TE topology represents S3 of the underlay TE topology in Figure 8. [Note that such a relationship is modeled via Supporting Node attribute of TE node S3' specifying the ID of S3, as well as the ID of the TE topology where S3 is defined (i.e. TE topology in Figure 8)]. Likewise, S9' represents S9, S11' represents S11 and so forth;

- o TE nodes S3', S5', S8', S9' and S11' are interconnected via a full mesh of abstract TE links. It is assumed that the provider's path computer can compute a set of optimal TE paths over one or more of underlay TE topologies (such as presented in Figure 8)- one for each of said abstract TE links; and the provider can set up the TE tunnels in the network supporting each of the abstract TE links, either during the abstract TE topology configuration (in the case of committed/pre-established abstract TE links), or at the time the first client's connection is placed on the abstract TE link in question (the case of uncommitted abstract TE links). [Note that so (re-)computed TE paths, as well as the IDs of respective underlay TE topologies used for their computation are normally catered to the client in the Underlay TE path attribute of the associated abstract TE links]

The configuration parameters of each of the abstract TE links (such as layer ID, bandwidth and protection requirements, preferred TE paths across the underlay TE topology for the primary and backup connections, etc.) are expected to be found in the abstract TE topology profiles/templates locally configured with the provider or pushed to the provider by the client via the policy NBI. Each of the abstract TE links may be later re-configured or removed by direct configuration requests issued by the client via TE Topology NBI. Likewise, additional abstract TE links may be requested by the client at any time.

Some possible variants/flavors of the Full Mesh Link Abstract TE Topology described above are:

- o Partial Mesh Link Abstract TE Topology (where some of the abstract TE links from the full mesh are missing);
- o Double Mesh Link Abstract TE Topology (where each pair of abstract TE nodes is connected via two diverse abstract TE links).

1.3.3. Star-n-Spokes Abstract TE Topology

Figure 12. Star-n-Spoke Abstract TE Topology

The Full Mesh Link Abstract TE Topology suffers from the n -squared problem; that is, the number of required abstract TE links is proportional to square of the number of native TE topology border TE nodes. This problem can be mitigated (i.e., the number of required abstract TE links may be significantly reduced) by adding, to the abstract TE topology, an additional abstract TE node (the star) representing one or several interconnected non-border TE nodes from the native TE topology. Abstract TE links in the Star-n-Spokes Topology connect the star with all other TE nodes of the topology (the spokes). For example, abstract TE node AN1 in Figure 12 could represent collectively TE nodes S7, S10 and S4 of the native TE topology (see Figure 8) with abstract TE links connecting AN1 with all other TE nodes in the Star-n-Spokes Abstract TE Topology in Figure 12.

In order to introduce a composite abstract TE node, (e.g. AN1 in Figure 12) representing in a given abstract TE topology an arbitrary segment of another TE topology (e.g. TE nodes S7, S12 and S4 of the TE topology in Figure 8) the TE topology provider is expected to perform the following operations:

- o Copy the TE topology segment to be represented by the abstract TE node (i.e. TE nodes S7, S10 and S4 in Figure 8, as well as the TE links interconnecting them) into a separate auxiliary TE topology (with a separate TE topology ID);

- o Set for each TE node and TE link of the auxiliary TE topology the Supporting Node/Link attribute matching the original TE topology ID, as well as the ID of the respective original TE node/link of the original TE topology. For example, if S7" of the auxiliary TE topology is a copy of S7 of the original TE topology, the Supporting Node attribute of S7" will specify the ID of the original TE topology (presented in figure 8) and the ID of S7;
- o Set for the abstract TE node AN1 the Underlay TE Topology attribute matching the auxiliary TE Topology ID

Furthermore, the Star-n-Spokes Abstract TE topology provider is expected to:

- o Compute/provision TE paths/tunnels supporting each of the abstract TE links in Figure 12 (i.e. abstract TE links connecting the spokes to the star, AN1) as described in 1.3.2;
- o Generate the AN1's Basic/Detailed Connectivity Matrix attribute based on intra-node path computations performed on the AN1's underlay (i.e. auxiliary) TE topology and describing permissible inbound TE link/label_x. outbound TE link/label_y switching combinations as described in 1.3.1

1.3.4. Arbitrary Abstract TE Topology

Figure 13. Arbitrary Abstract TE Topology

To achieve an optimal tradeoff between the number of components, the amount of information exposed by a transport network provider and the

amount of path computations required to keep said information up-to-date, the provider may present the TE network domain as an arbitrary abstract TE topology comprised of any number of abstract TE nodes interconnected by abstract TE links (see Figure 13). Each of the abstract TE nodes can represent a single or several interconnected TE nodes from the domain's underlay (native or lower level abstract) TE topology, or a fraction of an underlay TE node. [Note that each of the abstract TE nodes of the TE topology in Figure 13 is expected to be introduced and maintained by the provider following the instructions as described in 1.3.3; likewise, each of the abstract TE links of the topology is expected to be computed, provisioned and maintained as described in 1.3.2]

1.3.5. Customized Abstract TE Topologies

Figure 14. Customized Abstract TE Topology(ies)

A transport network/domain provider may serve more than one client. In such a case, the provider "slices" the network/domain resources and exposes a slice for each of the clients in the form of a customized abstract TE topology. In Figure 14, the provider serves

two clients (Blue and Red). Client Blue is provided with the Blue abstract TE topology supported by the blue TE tunnels or paths in the underlay (native) TE topology (depicted in the Figure with blue broken lines). Likewise, client Red is provided with the Red abstract TE topology supported by the red TE tunnels or paths in the underlay TE topology.

1.3.6. Hierarchical Abstract TE Topologies

Figure 15. Hierarchy of Abstract TE Topologies

As previously mentioned, an underlay TE topology for a given abstract TE topology component does not have to be one of the domain's native TE topologies - another (lower level) domain's abstract TE topology can be used instead. This means that abstract TE topologies are hierarchical in nature.

Figure 15 provides an example of abstract TE topology hierarchy. In this Figure the blue topology is a top level abstract TE topology catered to by the provider to one of the domain's clients. One of the TE links of the blue topology - link EF - is supported by a TE path E'-M-P-Q-N-F' computed in the underlay TE topology (red topology), which happens to be domain's (lower level) abstract TE topology.. Furthermore, as shown, the TE link PQ - one of the TE links comprising the E'-M-P-Q-N-F' path - is supported by its own underlay

TE path, P'-X-Q' - computed on one of the domain's native TE topologies.

Importantly, each TE link and TE node of a given abstract TE topology has, generally speaking, its individual stack/hierarchy of underlay TE topologies.

1.4. Merging TE Topologies Provided By Multiple Providers

A client may receive TE topologies provided by multiple providers, each of which managing a separate domain of an interconnected multi-domain transport network. In order to make use of said topologies, the client is expected to merge (inter-connect) the provided TE topologies into one or more client's native TE topologies, each of which homogeneously representing the multi-domain transport network. This makes it possible for the client to select end-to-end TE paths for its TE tunnel connections traversing multiple domains.

In particular, the process of merging TE topologies includes:

- o Identifying neighboring TE domains and locking their TE topologies horizontally by connecting their inter-domain open-ended TE links;
- o Renaming TE node, link, and SRLG IDs into ones allocated from a separate name space; this is necessary because all TE topologies are considered to be, generally speaking, independent with a possibility of clashes among TE node, link or SRLG IDs. Original TE node/link IDs along with the original TE topology ID are stored in the Source attribute of the respective TE nodes/links of the merged TE topology;
- o Locking, TE topologies associated with different layer networks vertically according to provided TE inter-layer locks; this is to facilitate inter-layer path computations across multiple TE topologies provided by the same topology provider.

Figure 16. Merging Domain TE Topologies

Figure 16 illustrates the process of merging, by the client, of TE topologies provided by the client's providers.

In the Figure, each of the two providers caters to the client a TE topology (abstract or native), describing the network domain under the respective provider's control. The client, by consulting the attributes of the open-ended inter-domain/access TE links - such as TE inter-domain plugs or remote TE node/link IDs - is able to determine that:

1. the two domains are adjacent and are interconnected via three inter-domain TE links, and;
2. each domain is connected to a separate customer site, connecting the left domain in the Figure to customer devices C-11 and C-12, and the right domain to customer devices C-21, C-22 and C-23.

Therefore, the client interconnects the open-ended TE links, as shown on the upper part of the Figure.

As mentioned, one way to interconnect the open-ended inter-domain/access TE links of neighboring domains is to mandate the providers to specify remote nodeID/linkID attributes in the provided inter-domain/access TE links. This, however, may prove to be not flexible. For example, the providers may not be aware of the respective remote nodeID/linkID values. More importantly, this option does not allow for the client to mix-n-match multiple (more than one) TE topologies catered by the same providers (see the next section). Another, more flexible, option to resolve the open-ended inter-domain/access TE links is by decorating them with the TE inter-domain plug attribute. The attribute specifies inter-domain plug ID - a network-wide unique value that identifies on the network connectivity supporting a given inter-domain/access TE link. Instead of specifying remote node ID/link ID, an inter-domain/access TE link may provide a non-zero inter-domain plug ID. It is expected that two neighboring domain TE topologies (provided by separate providers) will have each at least one open-ended inter-domain/access TE link with a TE inter-domain plug matching to one provided by its neighbor. For example, the inter-domain TE link originating from node S5 of the Domain 1 TE topology (Figure 8) and the inter-domain TE link coming from node S3 of Domain2 TE topology may specify matching TE inter-domain plugs (i.e. carrying the same inter-domain plug ID). This would allow for the client to identify adjacent nodes in the separate neighboring TE topologies and resolve the inter-domain/access TE links connecting them regardless of their respective nodeIDs/linkIDs (which, as mentioned, could be allocated from independent name spaces).

Inter-domain plug IDs may be assigned and managed by a central network authority. Alternatively, inter-domain plug IDs could be dynamically auto-discovered (e.g. via LMP protocol).

Furthermore, the client renames the TE nodes, links and SRLGs offered in the abstract TE topologies by assigning to them IDs allocated from a separate name space managed by the client. Such renaming is necessary, because the two abstract TE topologies may have their own name spaces, generally speaking, independent one from another; hence, ID overlaps/clashes are possible. For example, both TE topologies have TE nodes named S7, which, after renaming, appear in the merged TE topology as S17 and S27 respectively. IDs of the original (i.e. abstract TE topology) TE nodes/links along with the ID of the abstract TE topology they belong to are stored in the Source attribute of the respective TE nodes/links of the merged TE topology. For example, the Source attribute of S27 will contain S7 and the TE topology ID of the abstract TE topology describing domain 2.

Once the merging process is complete, the client can use the merged TE topology for path computations across both domains, for example, to compute a TE path connecting C-11 to C-23.

1.4.1. Dealing With Multiple Abstract TE Topologies Provided By The Same Provider

Figure 17. Multiple Abstract TE Topologies Provided By TE Topology Providers

A given provider may expose more than one abstract TE topology to the client. For example, one abstract TE topology could be optimized based on a lowest-cost criterion, while another one could be based on best possible delay metrics, while yet another one could be based on maximum bandwidth availability for the client connections. Furthermore, the client may request all or some providers to expose additional abstract TE topologies, possibly of a different type and/or optimized differently, as compared to already-provided TE topologies. In any case, the client should be prepared for a provider to offer to the client more than one abstract TE topology.

It should be up to the client to decide how to mix-and-match multiple abstract TE topologies provided by each of the providers, as well as how to merge them into the client's native TE topologies. The client also decides how many such merged TE topologies it needs to produce and maintain. For example, in addition to the merged TE topology depicted on the upper part of Figure 16, the client may merge the abstract TE topologies received from the two providers, as shown in Figure 17, into the client's additional native TE topologies, as shown in Figure 18.

[Note: allowing for the client mix-n-matching of multiple TE topologies assumes that TE inter-domain plugs (rather than remote nodeID/linked) option is used for identifying neighboring domains and inter-domain/access TE link resolution.]

Figure 18. Multiple Native (Merged) Client's TE Topologies

It is important to keep in mind that each of the three native (merged) TE topologies could be used by the client for computing TE paths for any of the multi-domain connections. The choice as to which topology to use for a given connection depends on the connection/tunnel parameters/requirements and the topology's style and optimization criteria.

1.5. Configuring Abstract TE Topologies

When a client receives one or more abstract TE topologies from one of its providers, it may accept the topologies as-is and merge them into one or more of its own native TE topologies. Alternatively, the client may choose to request a re-configuration of one, some or all abstract TE topologies provided by the providers. Specifically, with respect to a given abstract TE topology, some of its TE nodes/links may be requested to be removed, while additional ones may be requested to be added. It is also possible that existing TE nodes/links may be asked to be re-configured. For example, a set of TE links may be requested to be disjoint from each other by configuring the same Non Sharing Risk Link Group (NSRLG) attribute for all links from the set. Such a configuration would force the provider to place TE tunnels supporting the TE links from the set onto sufficiently disjoint TE paths computed in the tunnels underlay TE topology. Furthermore, the topology-wide optimization criteria may be requested to be changed. For example, underlay TE paths supporting the abstract TE links, currently optimized to be shortest (least-cost) paths, may be requested to be re-optimized based on the minimal delay criteria. Additionally, the client may request the providers to configure entirely new abstract TE topologies and/or to remove existing ones. Furthermore, future periodic or one time additions, removals and/or re-configurations of abstract TE topology elements and/or their attributes could be (re-)scheduled by the client ahead of time.

It is the responsibility of the client to implement the logic behind the above-described abstract TE topology negotiation. It is expected that the logic is influenced by the client's local configuration/templates, policies conveyed by client's clients, input from the network planning process, telemetry processor, analytics systems and/or direct human operator commands. Figure 19 exemplifies the abstract TE topology negotiation process. As shown in the Figure, the original abstract TE topology exposed by a provider was requested to be re-configured. Specifically, one of the abstract TE links was asked to be removed, while three new ones were asked to be added to the abstract TE topology.

Figure 19. Provider. Client Abstract TE Topology Negotiation

1.6. TE Tunnel Model

The TE Tunnel Model is written in YANG modeling language. It is defined and developed by the IETF TEAS WG and is documented as "YANG Data Model for Traffic Engineering Tunnels and Interfaces" [I-D.ietf-teas-yang-te]. Among other things the model describes a TE network provider's TE Tunnel data store as it is seen and influenced by a client.

The TE Tunnel Model allows for the provider to convey to each of its clients:

- o information on TE tunnels provided to the client that are fully contained within the controlled network domain,
- o information on multi-domain TE tunnel segments across the network domain controlled by the provider;
- o information on connections/LSPs, supporting TE tunnels and TE tunnel segments;
- o updates in response to changes to the client's active TE tunnels/segments and the connections supporting them,

- o updates in response to the TE tunnel/segment telemetry/state information the client has expressed an interest in.

The TE Tunnel Model allows for a TE network client to:

- o Issue configuration requests to set up, tear down, replace, modify and manipulate end-to-end TE tunnels, as well as segments of multi-domain TE tunnels across the network controlled by the provider;
- o Request and obtain information on active TE tunnels/segments and connections supporting them;
- o Subscribe to and configure with the provider triggers, pace and contents of the TE tunnel/segment change update notifications;
- o Subscribe to and configure with the provider triggers, pace and contents of the TE tunnel/segment event notifications, such as detected alarms, faults, protection/restoration actions, etc..
- o Subscribe to and configure with the provider triggers, pace and contents of TE tunnel/segment telemetry (e.g. statistics counters) update notifications.

1.7. TE Tunnel/Transport Service Modeling Constructs

Figure 20. TE tunnel

- o TE tunnel - a connection-oriented service provided by a layer network of delivery of a client's data between source and destination tunnel termination points. A TE tunnel in a server layer network may support a link in a client layer network (e.g. OCh layer TE tunnel supporting ODU4 link). In Figure 20, a TE tunnel interconnects tunnel termination points resident on switches C-R2 and C-R3. A TE tunnel is realized via (supported by, mapped onto) one or more layer network connections/LSPs

```
/* TE tunnel */
|  +--rw tunnel* [name]
|  |  +--rw name                               leafref
```



```

| | | |--rw identifier? leafref
/* TE tunnel configuration parameters */
| | | |--rw config
| | |   |--rw name? string
| | |   |--rw type? identityref
| | |   |--rw identifier? uint16
| | |   |--rw description? string
| | |   |--rw switchcap? identityref
| | |   |--rw encoding? identityref
| | |   |--rw protection-type? identityref
| | |   |--rw admin-status? identityref
| | |   |--rw preference? uint8
| | |   |--rw reoptimize-timer? uint16
| | |   |--rw source? inet:ip-address
| | |   |--rw destination? inet:ip-address
| | |   |--rw src-tp-id? binary
| | |   |--rw dst-tp-id? binary
id | | |   |--rw topology-id? te-types:te-topology-
| | |   |--rw ignore-overload? boolean
| | |   |--rw bandwidth-generic? te-types:te-bandwidth
disjointness | | |   |--rw disjointness? te-types:te-path-
| | |   |--rw setup-priority? uint8
| | |   |--rw hold-priority? uint8
| | |   |--rw signaling-type? identityref
/* Hierarchy TE tunnel parameters */
| | |   |--rw hierarchical-link-id
| | |     |--rw local-te-node-id? te-types:te-node-id
| | |     |--rw local-te-link-tp-id? te-types:te-tp-id
| | |     |--rw remote-te-node-id? te-types:te-node-id
topology-id | | |     |--rw te-topology-id? te-types:te-
/* Bidirectional TE tunnel parameters */
| | |   |--rw bidirectional
| | |     |--rw association
| | |       |--rw id? uint16
| | |       |--rw source? inet:ip-address
| | |       |--rw global-source? inet:ip-address
| | |       |--rw type? identityref
/* TE tunnel state */
| | |   |--ro state
| | |     |--ro name? string
| | |     |--ro type? identityref
| | |     |--ro identifier? uint16

```

```

| | | +--ro oper-status? identityref
/* TE tunnel primary path and LSP container */
| | | +--rw p2p-primary-paths
| | | +--rw p2p-primary-path* [name]
| | | +--rw name
| | | /* Configuration */
leafref
| | | +--rw config
| | | +--rw name? string
| | | +--rw preference? uint8
| | | +--rw path-setup-protocol? identityref
| | | +--rw path-computation-method? identityref
| | | +--rw path-computation-server? inet:ip-
address
| | | +--rw compute-only? empty
| | | +--rw use-cspf? boolean
| | | +--rw verbatim? empty
| | | +--rw lockdown? empty
| | | +--rw named-explicit-path? leafref
| | | +--rw named-path-constraint? leafref {te-
types:named-path-constraints}?
| | | /* state */
| | | +--ro state
| | | +--ro name? string
| | | +--ro preference? uint8
| | | +--ro path-setup-protocol? identityref
| | | +--ro path-computation-method? identityref
| | | +--ro path-computation-server? inet:ip-
address
| | | +--ro compute-only? empty
| | | +--ro use-cspf? boolean
| | | +--ro verbatim? empty
| | | +--ro lockdown? empty
| | | +--ro named-explicit-path? leafref
| | | +--ro named-path-constraint? leafref
{te-types:named-path-constraints}?
| | | /* Computed path */
| | | /* Computed path properties/metrics /
| | | +--ro computed-path-properties
| | | | +--ro path-metric* [metric-type]
| | | | | +--ro metric-type identityref
| | | | | +--ro accumulative-value? uint64
| | | /* Computed path affinities */
| | | +--ro path-affinities
| | | | +--ro constraints* [usage]
| | | | | +--ro usage?
identityref

```

```

| | | | | +-ro (style)?
| | | | | +---:(value)
| | | | | | +-ro value? te-
types:admin-groups
| | | | | +---:(named)
| | | | | | +-ro affinity-names*
[name]
| | | | | +-ro name string
/* Computed path SRLGs */
| | | | | +-ro path-srlgs
| | | | | | +-ro (style)?
| | | | | | +-ro usage? identityref
| | | | | | +-ro values* te-
types:srlg
| | | | | +---:(named)
| | | | | | +-ro constraints* [usage]
identityref
| | | | | | +-ro usage
| | | | | +-ro constraint
| | | | | | +-ro srlg-names* [name]
| | | | | | +-ro name string
/* Computed path sub-objects */
| | | | | +-ro path-computed-route-objects
.....
| | | | | /* LSP (provisioned path) */
lsp-id extended-tunnel-id type]
| | | | | +-ro lsp* [source destination tunnel-id
/* LSP parameters */
| | | | | +-ro source leafref
| | | | | +-ro destination leafref
| | | | | +-ro tunnel-id leafref
| | | | | +-ro lsp-id leafref
| | | | | +-ro extended-tunnel-id leafref
| | | | | +-ro type leafref
| | | | | +-ro signaling-type? identityref
+--rw candidate-p2p-secondary-paths
[secondary-path]
+--rw candidate-p2p-secondary-path*
| | | | | +-rw secondary-path leafref
| | | | | +-rw config
| | | | | | +-rw secondary-path? leafref
| | | | | | +-rw priority? uint16
| | | | | | +-rw path-setup-protocol?
identityref
| | | | | +-ro state
| | | | | | +-ro secondary-path? leafref

```

```

| | | |      +---ro priority?          uint16
identityref   +---ro path-setup-protocol?
| | | |      +---ro active?            boolean

/* TE tunnel secondary path and LSP container */

| | | |      +---rw p2p-secondary-paths
| | | | |    +---rw p2p-secondary-path* [name]
.....
| | | | |    +---rw name                leafref
| | | | |    +---rw config (same as for primary path )
.....
| | | | |    +---ro state (same as for primary, except for
disjointedness_state )
| | | | |    +---ro disjointness_state?        te-types:te-path-
disjointness.....
| | | | |    +---ro computed-path-properties (same as for
primary path)
.....
| | | | |    +---ro path-affinities (same as for primary
path)
.....
| | | | |    +---ro path-srlgs (same as for primary
path)
.....
| | | | |    +---ro path-computed-route-objects
.....
| | | | |    /* LSP (provisioned path) */
| | | | |    +---ro lsp (same as for the primary LSP)
.....

```

- o Tunnel termination point (TTP) - a physical device inside a given node/switch realizing a TE tunnel termination function in a given layer network, as well as the TE tunnel's adaptation function provided for client layer network(s). One example of tunnel termination point is an OCh layer transponder. [Note: Tunnel termination points are not to be confused with TE tunnel termination points, which are TE representations of physical tunnel termination points. Similar to physical switches and links of the network, such as depicted in Figure 20, being represented on a TE topology describing the network as TE nodes and TE links, (physical) tunnel termination points (TTPs) are represented as TE tunnel termination points (TE TTPs, see 1.2) hosted by the TE nodes. For example, a provisioned connection/LSP starts on a source TTP, goes through a chain of physical links and stops on a destination TTP. In contrast, TE path (e.g. result of a path computation) starts on a source TE TTP, goes through a chain of TE links and stops on a destination TE TTP.]

			---rw source?	inet:ip-address
			---rw destination?	inet:ip-address
			---rw src-tp-id?	binary
			---rw dst-tp-id?	binary

- o TE tunnel hand-off point - an access link or inter-domain link by which a multi-domain TE tunnel enters or exits a given network domain, in conjunction with a layer network resource (such as a wavelength channel or ODUk container) allocated on the access/inter-domain link for the TE tunnel.
- o TE tunnel segment - a part of a multi-domain TE tunnel that spans a given network domain and is directly and fully controlled by the domain's controller, DC. TE tunnel segment is a fragment of a multi-domain TE tunnel between
 1. the source tunnel termination point and the TE tunnel hand-off point outbound from the TE tunnel's first domain (head TE tunnel segment);
 2. inbound and outbound TE tunnel hand-off points into/from a given domain (transit TE tunnel segment);

3. inbound TE tunnel hand-off point into the TE tunnel's last domain and the destination tunnel termination point (tail TE tunnel segment);
- o Transport service - the same as TE tunnel segment
 - o Hierarchy TE tunnel - a server layer TE tunnel that supports a dynamically created TE link in the client layer network topology (e.g. see 1.2)

```

/* Hierarchy TE tunnel parameters */
      | | | | |
      | | | | | +--rw hierarchical-link-id
      | | | | | +--rw local-te-node-id?      te-types:te-node-id
      | | | | | +--rw local-te-link-tp-id?    te-types:te-tp-id
      | | | | | +--rw remote-te-node-id?     te-types:te-node-id
      | | | | | +--rw te-topology-id?        te-types:te-
topology-id

```

- o Hierarchy transport service - the first or the last segment of a multi-domain hierarchy TE tunnel
- o Dependency TE tunnel - a hierarchical TE tunnel provisioned or to be provisioned in an immediately adjacent server layer a given client layer TE tunnel depends on (i.e. carried or to be carried within)
- o Potential TE tunnel/segment - a TE tunnel/segment configured in COMPUTE_ONLY mode. For such a TE tunnel/segment TE paths to be taken by supporting connection(s) is/are computed and monitored, but the connection(s) are not provisioned

```

      | | | | |
      | | | | | +--rw path-computation-method? identityref
      | | | | | +--rw path-computation-server?  inet:ip-
address
      | | | | | +--rw compute-only?             empty
      | | | | | +--rw use-cspf?                 Boolean

```

Figure 20a. TE Tunnel Connections/LSPs

- o Layer network connection/connection/LSP - a layer network path supporting a TE tunnel by realizing its implied forwarding function. Said path is provisioned in a given layer network's data plane over a chain of links and cross-connected over switches terminating the links. It interconnects the supported TE tunnel's source and destination termination points (in the case of end-to-end connection) or TE tunnel's hand-off points (in the case of transport service connection) or the TE tunnel's two split-merge points (in the case of segment protection connection).

Example: ODU2 connection supporting an ODU2 TE tunnel.

				/* LSP (provisioned path) */	
				+--ro lsp* [source destination tunnel-id	
lsp-id	extended-tunnel-id	type]			
				/* LSP parameters */	
				+--ro source	leafref
				+--ro destination	leafref
				+--ro tunnel-id	leafref
				+--ro lsp-id	leafref
				+--ro extended-tunnel-id	leafref
				+--ro type	leafref
				+--ro signaling-type?	identityref
.....					
				+--ro priority?	uint16
				+--ro path-setup-protocol?	
identityref					
				+--ro active?	Boolean

- o Working connection - the primary connection of the supported TE tunnel or transport service (see Figure 20a).
- o End-to-end protection connection - a secondary end-to-end connection of the supported TE tunnel (e.g. end-to-end 1+1 protection connection, see Figure 20a).
- o Segment protection connection - a secondary connection of the supported transport service protecting the service over a given network domain (e.g. 1+1 segment protection connection, see Figure 20a)
- o Restored connection - a connection after successful network failure restoration procedures
- o Current connection - the same as restored connection
- o Nominal connection - a connection as (re-)provisioned upon a client configuration request (i.e. a connection before any automatic network failure restoration re-configurations are carried out, also a connection after restoration reversion procedures are successfully completed)
- o Unprotected TE tunnel/transport service - TE tunnel/transport service supported by a single (working/primary) connection/LSP

- o Protected TE tunnel/transport service - TE tunnel/transport service supported by one working connection/LSP and at least one protection/secondary connection/LSP
- o Restorable TE tunnel/transport service - TE tunnel/transport service with pre-configured automatic network failure restoration capabilities
- o TE tunnel/transport service automatic protection switchover - a process of switching of carrying user payload from the tunnel's/service's affected by a network failure working connection onto one of the tunnel's/service's healthy protection connection
- o TE tunnel/transport service automatic protection reversion - a process of switching of carrying user payload from the tunnel's/service's protection connection back onto the tunnel's/service's working connection after the latter was repaired from network failure
- o TE tunnel/transport service protection Hold-off time - a configured period of time to expire between the moment of detecting of the first network failure affecting the tunnel's/service's working connection and the beginning of the tunnel's/service's automatic protection switchover procedures
- o TE tunnel/transport service protection WTR time - a configured period of time to expire between the moment of repairing the last network failure affecting the tunnel's/service's working connection and the beginning of the tunnel's/service's automatic protection reversion procedures
- o TE tunnel/transport service automatic network failure restoration - a process of replacing of the tunnel's/service's connection(s) affected by one or more network failures away from the point(s) of failure
- o TE tunnel/transport service restoration reversion- a process of replacing of the tunnel's/service's connection(s) back onto the nominal connection paths after all network failures affecting the tunnel's/service's nominal connection(s) are repaired
- o TE tunnel/transport service restoration Hold-off time - a configured period of time to expire between the moment of detecting of the first network failure affecting the tunnel's/service's nominal or current connection and the beginning of the automatic connection restoration procedures

node-id					+++rw node-id?	te-types:te-
tp-id					+++rw link-tp-id?	te-types:te-
					+++rw hop-type?	te-hop-type
					+++:(label)	
					+++rw label-hop	
types:generalized-label					+++rw value?	rt-
					+++:(sid)	
					+++rw sid-hop	
types:generalized-label					+++rw sid?	rt-

- o Connection exclusion path - a TE path over a TE topology describing a layer network/domain that specifies the client's requirements with respect to an unordered list of network nodes, links and resources on the links to be avoided by a given connection

					+++rw route-object-exclude-always* [index]	
					+++rw index	leafref
					+++rw index?	uint32
					+++rw (type)?	
					+++:(numbered)	
					+++rw numbered-hop	
id					+++rw address?	te-types:te-tp-
					+++:(as-number)	
					+++rw as-number-hop	
					+++rw as-number?	binary
					+++:(unnumbered)	
					+++rw unnumbered-hop	
node-id					+++rw node-id?	te-types:te-
tp-id					+++rw link-tp-id?	te-types:te-
					+++:(label)	
					+++rw label-hop	
types:generalized-label					+++rw value?	rt-

```

      |           |   |   |
types:generalized-label  +--:(sid)
                        +--rw sid-hop
                        +--rw sid?   rt-

```

- o Connection computed path - a TE path over a TE topology describing a layer network/domain as computed (subject to all configured constraints and optimization criteria) for a given connection to take. Computed connection path could be thought as the TE path intended to be taken by the connection

```

/* Computed path */
/* Computed path properties/metrics /
    | | |
    | | | +---ro computed-path-properties
    | | |     +---ro path-metric* [metric-type]
    | | |         +---ro metric-type          identityref
    | | |         +---ro accumulative-value?   uint64
/* Computed path affinities */
    | | | +---ro path-affinities
    | | |     +---ro constraints* [usage]
    | | |         +---ro usage?
identityref
    | | |         +---ro (style)?
    | | |             +---:(value)
    | | |                 | +---ro value?          te-
types:admin-groups
    | | |             +---:(named)
    | | |                 +---ro affinity-names*
[name]
    | | |             +---ro name          string
/* Computed path SRLGs */
    | | | +---ro path-srlgs
    | | |     +---ro (style)?
    | | |         +---:(values)
    | | |             +---ro usage?          identityref
    | | |             +---ro values*        te-
types:srlg
    | | |         +---:(named)
    | | |             +---ro constraints* [usage]
identityref
    | | |                 +---ro usage

```

```
| | | | | +--ro constraint  
| | | | | +--ro srlg-names* [name]  
| | | | | +--ro name string  
/* Computed path sub-objects */  
| | | | | +--ro path-computed-route-objects
```

.....

- o Connection actual path - an active connection's path as provisioned in the layer network's data plane in the form of a TE path over a TE topology describing the layer network/domain

1.8. Transport Service Mapping

Figure 21. Transport Service Mapping

Let's assume that a provider has exposed to a client its network domain in the form of an abstract TE topology, as shown on the left side of Figure 21. From then on, the provider should be prepared to receive from the client, a request to set up or manipulate a transport service with TE path(s) computed for the service connection(s) based on and expressed in terms of the provided abstract TE topology (as, for example, displayed in red broken line on the right side of Figure 21). When this happens, the provider is expected to set up the TE tunnels supporting all yet uncommitted abstract TE links (e. g, TE link S3'-S8' in the Figure).

Furthermore, it is the responsibility of the provider to:

- o Perform all the necessary abstract-to-native translations for the specified TE paths (i.e. the transport service connection configured paths);

- o Provision working and protection connections supporting the transport service; as well as replace/modify/delete them in accordance with subsequent client's configuration requests;
- o Perform all the requested recovery operations upon detecting network failures affecting the transport service;
- o Notify the client about all parameter changes, events and other telemetry information the client has expressed an interest in, with respect to the transport service in question.

1.9. Multi-Domain Transport Service Coordination

A client of multiple TE network domains may need to orchestrate/coordinate its transport service setup/manipulation across some or all the domains. One example of such a client is a Hierarchical T-SDN Controller, HC, managing a connected multi-domain transport network where each of the domains is controlled by a separate Domain T-SDN Controller, DC. Said DCs are expected to expose TE Topology and TE Tunnel North Bound Interfaces, NBIs,, supported respectively by IETF TE Topology and TE Tunnel models (and their network layer specific augmentations). HC is assumed to establish client-provider relationship with each of the DCs and make use of said NBIs to extract from the domains various information (such as TE topologies and telemetry), as well as to convey instructions to coordinate across multiple domains its transport services set up and manipulation.

Figure 22. Two-Domain Transport Network

Let's consider, for example, a two-domain transport network as represented in Figure 22. Suppose that HC is requested to set up an unprotected transport service to provide connectivity between customer network elements C-R1 and C-R6. It is assumed that by the time the request has arrived, the two DCs have already provided abstract TE topologies describing their respective domains, and that HC has merged the provided TE topologies into one that homogeneously describes the entire transport network (as shown in Figure 23).

Figure 23. Two-Domain Transport Network (Abstracted View)

Consider that HC, using the merged TE topology, selected a TE path to be taken by the requested transport service connection as shown on the upper part of Figure 24.

The multi-domain transport service set up coordination includes:

- o Splitting selected for the transport service TE path(s) into segments - one set of segments per each domain involved in the service setup;
- o Issuing a configuration request to each of the involved DCs to set up the transport service across the respective domain. Note that the connection configured paths are required to be expressed in terms of respective abstract TE topologies as exposed to HC by DCs (see lower part of Figure 24).

- o Waiting for the set up complete confirmation from each of the involved DCs. In case one of the DCs reports a failure, HC is responsible to carry out the cleanup/rollback procedures by requesting all involved DCs to tear down the successfully created segments

Figure 24. Transport Service Placement Based on Abstract TE Topology

While processing the received from HC configuration request to set up the transport service, each DC is expected to carry out the transport service mapping procedures (as described in 1.8) resulting in the set up of all the necessary underlay TE tunnels, as well as one or more connections supporting the transport service. As a result, the requested transport service will be provisioned as shown in Figure 25.

The multi-domain transport service tear down coordination entails issuing to each of the involved DCs a configuration request to delete the transport service in the controlled by the DC domain. DCs are

expected in this case to release all network resources allocated for the transport service.

The multi-domain transport service modify coordination implies issuing to each of the involved DCs a configuration request to replace the transport service connections according to the newly provided paths and/or modify the connection parameters according to the newly provided configuration.

Figure 25. Multi-domain transport service is provisioned

2. Use Cases

2.1. Use Case 1. Transport service control on a single layer multi-domain transport network

Configuration (Figure 26):

- o Three-domain multi-vendor ODUk/Och transport network;
- o The domains are interconnected via ODUk inter-domain links;
- o Each of the domains is comprised of ODUk/Och network elements (switches) from a separate vendor and is controlled by a single (vendor specific) T-SDN Domain Controller (DC);
- o All DCs expose IETF TE Topology and TE Tunnel model based NBIs;
- o The transport network as a whole is controlled by a single hierarchical T-SDN controller (HC);
- o HC makes use of the NBIs to set up client-provider relationship with each of the DCs and controls via the DCs their respective network domains;
- o Three customer IP/MPLS sites are connected to the transport network via ODUk access links;
- o The customer IP/MPLS routers and the router transport ports connecting the routers to the transport network are managed autonomously and independently from the transport network.

Figure 26 Three-domain ODUk/Och transport network with ODUk access and inter-domain links

Objective: Set up/manipulate/delete a shortest delay unprotected or protected transport service to provide connectivity between customer network elements C-R2 and C-R5

1) TE Topology discovery

All DCs provide to HC respective domain ODUk layer abstract TE topologies. Let's assume that each such topology is a single-node TE topology (as described in 1.3.1, abstract TE topology of this type represents the entire domain as a single asymmetrical/blocking TE node). Let's further assume that the abstract TE nodes representing the domains are attributed with detailed connectivity matrices optimized according to the shortest delay criterion. [Note: single-node abstract TE topologies are assumed for simplicity sake. Alternatively, any DC could have provided an abstract TE topology of any type described in 1.3].

HC merges the provided TE topologies into its own native TE topology (the TE topology merging procedures are discussed in 1.4). The merged TE topology, as well as the TE topologies provided by DCs, are depicted in Figure 27. The merged TE topology homogeneously describes the entire transport network and hence is suitable for path computations across the network. Note that the dotted lines in the Figure connecting the topology access TE links with customer devices illustrate that HC in this use case has neither control nor information on the customer devices/ports and, therefore, can only provide a connectivity between the requested transport service ingress and egress access links (on assumption that the customer transport ports are provisioned independently)

Figure 27. Three-domain single layer transport network abstract TE topology

2) Transport service path computation

Using the merged TE topology (Figure 27, upper part) HC selects one or more optimal and sufficiently disjoint from each other TE path(s) for the requested transport service connection(s). Resulting TE paths for the requested end-to-end protected transport service, for example, could be as marked on the upper part of Figure 28.

It is important to keep in mind that HC's path computer is capable of performing the necessary path selection only as long as the merged TE topology provides the necessary TE visibility for the path selection, both intra-domain (e.g. by virtue of provided by the abstract TE nodes detailed connectivity matrices) and inter-domain (because of provided inter-domain TE link attributes). In case one or more DCs is/are not capable of or willing to provide the detailed connectivity matrices (that is, DCs expose the respective domains as black boxes - unconstrained TE nodes terminating the inter-domain TE links), HC will not be able to select the end-to-end TE path(s) for the requested transport service on its own. In such a case HC may opt for making use of the Path Computation NBI, exposed by the DCs to explore/evaluate intra-domain TE path availability in real time. IETF TE Tunnel model supports the Path Computation NBI by allowing for the configuration of transport services in COMPUTE_ONLY mode. In this mode the provider is expected to compute TE paths for a requested transport service connections and return the paths in the request's response without triggering the connection provisioning in the network.

Consider, for example, the case when none of the DCs has provided the detailed connectivity matrix attribute for the abstract TE nodes representing the respective domain. In such a case HC may:

1. Request the ingress domain DC (i.e. DC1) to compute intra-domain TE paths connecting the ingress access TE link (i.e. the link facing C-R2) with each of the inter-domain TE links (i.e. links connecting Domain 1 to Domain 2 and Domain 3 respectively);
2. Grow the TE paths returned by DC1 in (1) over the respective outbound inter-domain TE links;
3. Request the neighboring DC(s) (e.g. DC3) to compute all intra-domain TE paths connecting across the domain all inbound into the domain inter-domain TE links reached by the path growing process in (2) with all other (outbound) domain's inter-domain TE links;

4. Augment the TE paths produced in step (2) with the TE paths determined in step (3);
5. Repeat steps (2), (3) and (4) until the resulting TE paths reach the egress domain (i.e. Domain 2);
6. Request the egress domain DC (i.e. DC2) to grow each of the TE paths across the domain to connect them to the egress access TE link (i.e. the link facing C-R5);
7. Select one (or more) most optimal and sufficiently disjoint from each other TE path(s) from the list produced in step (6).

[Note: The transport service path selection method based on Path Computation NBIs exposed by DCs does not scale well and the more domains comprise the network and the more inter-domain links interconnect them, the worse the method works. Realistically, this approach will not work sufficiently well for the networks with more than 3 domains]

Figure 28. TE paths computed for the protected transport service

3) Transport service setup coordination

HC carries out the multi-domain transport service setup coordination as described in 1.9. In particular, HC splits the computed TE path(s) into 3 sets of TE path segments - one set per domain (as shown on the lower part of Figure 28), and issues a TE tunnel configuration request to each of the DCs to set up the requested transport service across the domain under the DC's control. The primary (and secondary) connection explicit path(s) is/are specified in the requests in terms of respective domain abstract TE topologies.

While processing the configuration request, each DC performs the transport service mapping (as described in 1.8). In particular, the DC translates the specified explicit path(s) from abstract into native TE topology terms, sets up supporting underlay TE tunnels

(e.g. Och TE tunnels), and, then, allocates required ODUk containers on the selected links and provisions the ODUk cross-connects on the switches terminating the links.

If the setup is successfully completed in all three domains, the transport service connection(s) will be provisioned as depicted in Figure 29. If one of the DCs fails to set up its part, all successfully provisioned segments will be asked by HC to be released.

4) Transport service teardown coordination

HC issues to each of DCs a configuration request to release the transport service over the controlled domain, as well as the server layer TE tunnels supporting dynamically created links.

Figure 29. Transport service is provisioned

2.2. Use Case 2. End-to-end TE tunnel control on a single layer multi-domain transport network

Configuration (Figure 26): the same as in use case 1, except that HC in this use case controls customer devices/ports by extracting information from and pushing configuration to the customer site SDN controller(s) managing the customer devices directly.

Objective: Set up//delete an unprotected shortest delay TE tunnel interconnecting end-to-end C-R2 and C-R5

1) TE Topology discovery

As in use case 1 all DCs provide to HC domain ODUk layer abstract TE topologies. Additionally in this use the three customer site controllers expose the TE Topology and Tunnel model based NBIs to HC. Using the TE Topology NBI each customer controller provides to HC the respective customer site domain abstract TE topology. Customer site abstract TE topologies contain abstract TE nodes representing the devices which are directly connected to the transport network. Said abstract TE nodes host TE tunnel termination points, TTPs, representing the ports over which the customer devices are connected to the transport network, and terminate access TE links the TTPs are accessible from (see Figure 30).

Figure 30. Abstract TE topologies provided by all network domains and customer sites

HC merges the provided topologies into its own native TE Topology (the TE topology merging procedures are discussed in 1.4). The merged TE topology is depicted in Figure 31. It homogeneously describes end-to-end not only the entire transport network, but also the customer sites connected to the network and hence is suitable for TE tunnel end to end path computations.

Figure 31. Abstract TE topology describing transport network and connected to it customer sites

2) TE tunnel path computation

Using the merged TE topology (Figure 31) HC selects an optimal TE path for the requested TE tunnel connecting end-to-end the specified TE tunnel termination points, TTPs. The resulting TE path, for example, could be as marked on the upper part of Figure 32.

Figure 32. TE path computed for the TE tunnel

3) TE tunnel setup coordination

HC carries out the multi-domain TE tunnel setup coordination as described for use case 1, except that in this use case HC additionally initiates and controls the setup of the TE tunnel's head and tail segments on the respective customer sites. Note that the customer site controllers behave exactly as transport network domain DCs. In particular, they receive issued by HC configuration requests to set up the TE tunnel's head and tail segments respectively. While processing the requests the customer site controllers perform the necessary provisioning of the TE tunnel's source and destination termination points, as well as of the local sides of the selected

access links. If all segments are successfully provisioned on customer sites and network domains, the TE tunnel connection will be provisioned as marked in Figure 33.

4) TE tunnel teardown coordination

HC issues to each of DCs and customer site controllers a configuration request to release respective segments of the TE tunnel, as well as the server layer TE tunnels supporting dynamically created links.

Figure 33. TE tunnel is provisioned

2.3. Use Case 3. Transport service control on a ODUk/Och multi-domain transport network with Ethernet access links

Configuration (Figure 34): the same as in use case 1, except that all access links in this use case are Ethernet layer links (depicted as

blue lines in the Figure), while all inter-domain links remain to be ODUk layer links.

Figure 34. Three-domain ODUk/Och transport network with Ethernet layer access links

Objective: Set up/delete an unprotected shortest delay transport service supporting connectivity between C-R2 and C-R5

1) TE Topology discovery

In order to make possible for the necessary in this use case multi-layer path computation, each DC exposes to HC two (ODUk layer and Ethernet layer) abstract TE topologies. Additionally, the lower layer (ODUk) TE nodes announce hosted by them TE tunnel termination points, TTPs, capable of adopting the payload carried over the Ethernet layer access links. From the TE Topology model point of view this means that said TTPs are attributed with TE inter-layer locks

matching ones attributed to Ethernet TE links (i.e. TE links provided within Ethernet layer abstract TE topologies).

Ethernet and ODUk layer single node abstract TE topologies catered to HC by each of the DCs are presented in Figure 35.

HC merges the provided TE topologies into its own native TE Topology (the merging procedures are described in 1.4). Importantly in this case HC locks the provided TE topologies not only horizontally, but vertically as well, thus producing a two-layer TE topology homogenously describing both layers of the entire transport network, as well as the client-server layer adaptation relationships between the two layers. This makes the merged TE topology suitable for multi-layer/inter-layer multi-domain transport service path computations. The merged TE topology is presented in Figure 36.

Figure 35. ODUk and Ethernet layer abstract TE topologies exposed by DCs

Figure 36. Two-layer three-domain transport network abstract TE topology

2) Transport service path computation

Using the merged TE topology (Figure 36) HC selects an optimal TE path for the requested transport service.

Note that if HC's path computer considered only Ethernet layer TE nodes and links, the path computation would fail. This is because the Ethernet layer TE nodes (i.e. D1-e, D2-e and D3-e in the Figure) are disconnected from each other. However, the inter-layer associations (in the form of the TE inter-layer links) make possible for the path computer to select TE path(s) in the lower (ODUk) layer that can be used to set up hierarchy TE tunnel(s) supporting additional dynamic TE link(s) in the upper (Ethernet) layer in order for the requested transport service path computation to succeed.

Let's assume that the resulting TE path is as marked in Figure 37. The red line in the Figure marks the TE path selected for the ODUk layer hierarchy TE tunnel supporting the required Ethernet layer dynamic TE link.

Figure 37. Multi-layer TE path computed for the transport service

3) Transport service setup coordination

HC sets up the requested Ethernet layer transport service in two stages. First, it coordinates the end-to-end setup of the ODUk layer hierarchy TE tunnel between the selected TTPs. If this operation succeeds, a new Ethernet layer dynamic TE link (blue line connecting TE nodes D1-e and D2-e in Figure 38) is automatically added to the merged abstract TE topology. Importantly, as a part of the hierarchy transport service setup both DC1 and DC 2 add a new open-ended Ethernet layer inter-domain dynamic TE link to their respective abstract TE topologies. Second, HC coordinates the setup of the requested (Ethernet layer) transport service. The required TE path for the second stage is marked as fat blue line in the Figure. Note that DC3 controlling domain 3 is only involved in the first stage, but is oblivious to the second stage.

Figure 38. A new Ethernet layer TE link supported by ODUk layer TE tunnel is added to the provided and merged abstract TE topologies

IF all involved DCs confirm successful setup completion, the requested transport service, as well as the supporting server layer hierarchy TE tunnel, will be provisioned as depicted in Figure 39. If one of the DCs fails to set up its segment in either of the layers, all successfully provisioned segments will be requested by HC to be released.

Figure 39. Ethernet transport service and supporting ODUk TE tunnel are provisioned

4) Transport service teardown coordination

First, HC issues to DC1 and DC2 a configuration request to release the Ethernet layer transport service in the respective domains. After that, all three DCs are requested to release the segments of the supporting ODUk layer hierarchy TE tunnel. While processing the request DC1 and DC2 also remove the dynamic Ethernet layer TE links supported by the respective hierarchy TE tunnel's segments, thus the

network's abstract TE topologies are reverted back to the state as shown in Figures 35 and 36.

2.4. Use Case 4. Transport service control on a ODUk/Och multi-domain transport network with multi-function access links

Configuration (Figure 40): the same as in use case 3, except that all access links in this use case are multi-function links (depicted in the Figure as blue compound lines). Let's assume that, depending on configuration, the multi-function access links in this use case can carry either Ethernet or SDH/STM16 layer payload.

Objective: Set up/delete an unprotected shortest delay SDH/STM16 layer transport service interconnecting C-R2 and C-R5

Figure 40. Three-domain ODUk/Och transport network with multi-function access links

1) TE Topology discovery

The TE Topology model considers multi-function links as parallel mutually exclusive TE links each belonging to a separate layer network. For this use case each DC exposes to HC three (ODUk-, Ethernet- and SDH/STM16-layer) abstract TE topologies (generally speaking, one abstract TE topology per each layer network supported by at least one access or inter-domain link). Like in use case 3, the lower layer (ODUk) TE nodes announce hosted by them TE tunnel termination points, TTPs, capable in this case of adopting Ethernet, SDH/STM16 or both layer payloads, The TTPs are attributed with TE inter-layer links matching ones specified for Ethernet and/or SDH/STM16 TE links.

Ethernet, SDH/STM16 and ODUk layer single-node abstract TE topologies catered to HC by each of the DCs are presented in Figure 41.

HC merges the provided topologies into its own native TE Topology (the merging procedures are described in 1.4). As in use case 3 HC locks the provided TE topologies not only horizontally (i.e. between domains), but vertically (between layers) as well, thus producing a three-layer TE topology homogenously describing the three layers of the entire transport network, as well as the client-server layer adaptation relationships between the layers. This makes the merged TE topology suitable for multi-layer/inter-layer multi-domain transport service path computations. The merged TE topology is presented in Figure 42.

Figure 41. ODUk, Ethernet and SDH/STM16 layer abstract TE topologies exposed by DCs

Figure 42. Three-layer three-domain transport network abstract TE topology

2) Transport service path computation

Using the merged TE topology (Figure 42) HC's path computer selects a TE path for the requested transport service. For example, for the SDH/STM16 layer unprotected transport service the resulting TE path could be determined as marked in Figure 43.

Figure 43. Multi-layer TE path computed for SDH/STM16 layer transport service

3) Transport service setup coordination

Same as in use case 3.

4) Transport service teardown coordination

Same as in use case 3.

2.5. Use Case 5. Real time updates of IP/MPLS layer TE link attributes that depend on supporting transport connectivity (e.g. transport SRLGs, propagation delay, etc.)

Configuration (Figure 26): the same as in use case 1,

Objective: A transport service interconnecting transport ports of two IP routers across a transport network is likely to serve a link in IP/MPLS layer network, which is usually controlled by a client of the

transport network, such as IP/MPLS Controller. Performance of TE applications (e.g. path computer) running on the IP/MPLS Controller depends on the accuracy of IP/MPLS layer TE link attributes. Some of these attributes can change over time and are known real-time only to a transport network controller, such as HC. Examples of said attributes are transport SRLGs, propagation delay metric, protection capacities and status, etc. The objective of this use case is to ensure up-to-date state of said attributes in the IP/MPLS Controller's internal TED via necessary updates provided in a timely manner by the controller (e.g. HC) managing transport connectivity supporting IP/MPLS layer links.

Realization:

- o HC exposes and supports IETF TE Topology and TE Tunnel model based NBIs (the same NBIs that are exposed by DCs serving HC);
- o IP/MPLS Controller makes use of the exposed NBIs to set up the respective client-provider relationships with HC;
- o IP/MPLS Controller uses the TE Tunnel NBI to configure with HC a transport service interconnecting transport ports of a pair of IP routers desired to be adjacent in the IP/MPLS layer network. The TE Tunnel model allows for specifying in the transport service configuration request the TE topology and link IDs of the IP/MPLS TE link the requested transport service will be serving;
- o IP/MPLS Controller uses the TE Topology NBI to subscribe with HC on the IP/MPLS TE link notifications with respect to changes in the TE link's attributes, such as SRLGs, propagation delay, protection capabilities/status, etc.;
- o HC uses the TE Topology NBI to convey the requested notifications when HC learns the attributes IP/MPLS has expressed interest in or detects any changes since previous notifications (for example, due to network failure restoration/reversion procedures happened to the transport connectivity that supports the failure affected IP/MPLS links)

2.6. Use Case 6. Virtual Network Service

Configuration (Figure 26): the same as in use case 1,

Objective: Set up two Virtual Networks for the client, with Virtual Network 1 interconnecting customer IP routers C-R1, C-R7 and C-R4 over a single-node abstract TE topology, and Virtual Network 2

interconnecting customer IP routers C-R2, C-R3, C-R8, C-R5 and C-R6 over a full mesh link abstract TE topology as depicted in Figure 44.

[Note: A client of a transport network may want to limit the transport network connectivity of a particular type and quality within distinct subsets of its network elements interconnected across the transport network. Furthermore, a given transport network may serve more than one client. In this case some or all clients may want to ensure the availability of transport network resources in case dynamic (re-)connecting of their network elements across the transport network is envisioned. In all such cases a client may want to set up one or more Virtual Networks over provided transport network]

1) Virtual Network setup

From the client's point of view a Virtual Network setup includes the following procedures:

- o Identifying the Virtual Network membership - a subset of the client's network elements/ports to be interconnected over the abstract TE topology configured for the Virtual Network. Note that from the transport network provider's point of view this effectively determines the list of abstract TE topology's open-ended access TE links;
- o Deciding on the Virtual Network's abstract TE topology type (e.g. single-node vs. link mesh), optimization criterion (e.g. shortest delay vs. smallest cost), bandwidth, link disjointedness, adaptation capabilities and other requirements/constraints, as well as, whether the TE tunnels supporting the abstract TE topology need to be pre-established or established on demand (i.e. when respective abstract TE topology elements are selected for a client transport service);
- o Using the IETF TE Topology model based NBI exposed by the transport network controller (i.e. HC), configure the Virtual Network's abstract TE topology. Let's assume that in this use case the abstract TE topology for Virtual Network 1 is configured as a single-node abstract TE topology (see section 1.3.1) with the abstract TE node's detailed connectivity matrix optimized according to the shortest delay criteria. Likewise, the abstract TE topology for Virtual Network 2 is configured as a full-mesh link abstract TE topology (see section 1.3.2) optimized according to the smallest cost criteria with each of the abstract TE links to be supported by pre-established end-to-end protected TE tunnels.

[Note: Virtual Network's abstract TE topology (re-)configuration/negotiation process is no different from one that happens, for example, between HC and its providers, DCs, and is described in section 1.5]

Figure 44. Virtual Networks provided for a transport network client

2) Using Virtual Network

Recall that use case 1 was about setting up a transport service interconnecting customer network elements C-R2 and C-R5 across the transport network. With the Virtual Network 2 in place, the client could have used the Virtual Network's TE topology to select a TE path for the service. The TE Tunnel model based NBI allows for the client to specify the Virtual Network's TE topology ID, as well, as the selected TE path (for example, as marked in Figure 45) as a configured path attribute in the transport service configuration request to ensure that the intended transport network resources are used for the service.

Figure 45. Transport service TE path is selected on Virtual Network's TE topology

3. Security Considerations

This document does not define networking protocols and data, hence are not directly responsible for security risks.

4. IANA Considerations

This document has no actions for IANA.

5. References

5.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[I-D.ietf-teas-yang-te-topo]
Liu, X., Bryskin, I., Beeram, V., Saad, T., Shah, H., and
O. Dios, "YANG Data Model for TE Topologies", draft-ietf-
teas-yang-te-topo-08 (work in progress), March 2017.

[I-D.ietf-teas-yang-te]

Saad, T., Gandhi, R., Liu, X., Beeram, V., Shah, H., and I.
Bryskin, "A YANG Data Model for Traffic Engineering Tunnels
and Interfaces", draft-ietf-teas-yang-te-06 (work in
progress), March 2017.

5.2. Informative References

[RFC2702] Awduche, D., "Requirements for Traffic Engineering Over MPLS", RFC 2702, September 1999.

6. Acknowledgments

TBD.

Appendix A.

Data Examples

This section contains examples of an instance data in the JSON encoding [RFC7951].

A.1. Use Case 1

In the use case described in Section 2.1. , there are three provider network domains, each of them is represented as an abstract TE topology. The JSON encoded example data configurations for the three domains are:

A.1.1. Domain 1

```
{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {}
        },
        "network-id": "otn-domain1-abs",
        "provider-id": 201,
        "client-id": 300,
        "te-topology-id": "te-topology:otn-domain1-abs",
        "node": [
          {
            "node-id": "D1",
            "te-node-id": "2.0.1.1",
            "te": {
              "te-node-attributes": {
                "domain-id" : 1,
                "is-abstract": [null],
                "underlay-topology": "domain1-och",
                "connectivity-matrices": {
                  "is-allowed": true,
                  "path-constraints": {
                    "bandwidth-generic": {
                      "te-bandwidth": {
                        "otn": [
                          {
                            "rate-type": "odul",
                            "counter": 2
                          }
                        ]
                      }
                    }
                  }
                }
              }
            }
          ]
        }
      ]
    }
  }
}
```

```
    }  
  ]  
}  
}  
}  
"connectivity-matrix": [  
  {  
    "id": 10302,  
    "from": "1-0-3",  
    "to": "1-2-0"  
  },  
  {  
    "id": 10203,  
    "from": "1-0-2",  
    "to": "1-3-0"  
  },  
  {  
    "id": 10311,  
    "from": "1-0-3",  
    "to": "1-11-0"  
  },  
  {  
    "id": 11103,  
    "from": "1-0-11",  
    "to": "1-3-0"  
  },  
  {  
    "id": 10903,  
    "from": "1-0-9",  
    "to": "1-3-0"  
  },  
  {  
    "id": 10309,  
    "from": "1-0-3",  
    "to": "1-9-0"  
  },  
  {  
    "id": 10910,  
    "from": "1-0-9",  
    "to": "1-10-0"  
  },  
],
```

```

        {
            "id": 11009,
            "from": "1-0-10",
            "to": "1-9-0"
        },
        {
            "id": 20910,
            "from": "1-1-9",
            "to": "1-10-0"
        },
        {
            "id": 21009,
            "from": "1-0-10",
            "to": "1-9-1"
        },
        {
            "id": 20911,
            "from": "1-1-9",
            "to": "1-11-0"
        },
        {
            "id": 21109,
            "from": "1-0-11",
            "to": "1-9-1"
        }
    ]
}
},
"termination-point": [
    {
        "tp-id": "1-0-3",
        "te-tp-id": 10003
        "te": {
            "interface-switching-capability": [
                {
                    "switching-capability": "switching-otn",
                    "encoding": "lsp-encoding-oduk"
                }
            ]
        }
    }
]
}

```



```
    },
    {
      "tp-id": "1-3-0",
      "te-tp-id": 10300
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ],
  {
    "tp-id": "1-0-9",
    "te-tp-id": 10009
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  }
],
{
  "tp-id": "1-9-0",
  "te-tp-id": 10900
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
}
],
{
  "tp-id": "1-1-9",
  "te-tp-id": 10109
  "te": {
```

```
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      },
    },
    {
      "tp-id": "1-9-1",
      "te-tp-id": 10901
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    },
    {
      "tp-id": "1-0-2",
      "te-tp-id": 10002
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    },
    {
      "tp-id": "1-2-0",
      "te-tp-id": 10200
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ]
}
```

```
    ]
  },
  {
    "tp-id": "1-0-10",
    "te-tp-id": 10010
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-10-0",
    "te-tp-id": 11000
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-0-11",
    "te-tp-id": 10011
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-11-0",
```

```

    "te-tp-id": 11100
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-1-11",
    "te-tp-id": 10111
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-11-1",
    "te-tp-id": 11101
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  }
]
}
}
}
}
}
}
}
}
}
}

```

A.1.1.2. Domain 2

```
{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {}
        },
        "network-id": "otn-domain2-abs",
        "provider-id": 202,
        "client-id": 300,
        "te-topology-id": "te-topology:otn-domain2-abs",
        "node": [
          {
            "node-id": "D2",
            "te-node-id": "2.0.2.2",
            "te": {
              "te-node-attributes": {
                "is-abstract": [null],
                "underlay-topology": "domain2-och",
                "connectivity-matrices": {
                  "is-allowed": true,
                  "path-constraints": {
                    "bandwidth-generic": {
                      "te-bandwidth": {
                        "otn": [
                          {
                            "rate-type": "odul",
                            "counter": 2
                          }
                        ]
                      }
                    }
                  }
                }
              }
            }
          ]
        },
        "connectivity-matrix": [
          {
            "id": 12125,
            "from": "1-0-21",
            "to": "1-25-0"
          }
        ],
      }
    ]
  }
}
```

```
{
  "id": 12521,
  "from": "1-0-25",
  "to": "1-21-0"
},
{
  "id": 12128,
  "from": "1-0-21",
  "to": "1-28-0"
},
{
  "id": 12821,
  "from": "1-0-28",
  "to": "1-21-0"
},
{
  "id": 12231,
  "from": "1-0-22",
  "to": "1-31-0"
},
{
  "id": 13122,
  "from": "1-0-31",
  "to": "1-22-0"
},
{
  "id": 22228,
  "from": "1-1-22",
  "to": "1-28-0"
},
{
  "id": 22822,
  "from": "1-0-28",
  "to": "1-22-1"
},
{
  "id": 12528,
  "from": "1-0-25",
  "to": "1-28-0"
},
{
```

```
        "id": 12825,  
        "from": "1-0-28",  
        "to": "1-25-0"  
      }  
    ]  
  }  
},  
"termination-point": [  
  {  
    "tp-id": "1-0-21",  
    "te-tp-id": 10021  
    "te": {  
      "interface-switching-capability": [  
        {  
          "switching-capability": "switching-otn",  
          "encoding": "lsp-encoding-oduk"  
        }  
      ]  
    }  
  },  
  {  
    "tp-id": "1-21-0",  
    "te-tp-id": 12100  
    "te": {  
      "interface-switching-capability": [  
        {  
          "switching-capability": "switching-otn",  
          "encoding": "lsp-encoding-oduk"  
        }  
      ]  
    }  
  },  
  {  
    "tp-id": "1-0-22",  
    "te-tp-id": 10022  
    "te": {  
      "interface-switching-capability": [  
        {  
          "switching-capability": "switching-otn",  
          "encoding": "lsp-encoding-oduk"  
        }  
      ]  
    }  
  }  
]
```

```

    }
  ]
}
},
{
  "tp-id": "1-22-0",
  "te-tp-id": 12200
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
},
{
  "tp-id": "1-1-22",
  "te-tp-id": 10122
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
},
{
  "tp-id": "1-22-1",
  "te-tp-id": 12201
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
},
},
{

```



```
"tp-id": "1-0-25",
"te-tp-id": 10025
"te": {
  "interface-switching-capability": [
    {
      "switching-capability": "switching-otn",
      "encoding": "lsp-encoding-oduk"
    }
  ]
}
},
{
  "tp-id": "1-25-0",
  "te-tp-id": 12500
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
},
{
  "tp-id": "1-1-25",
  "te-tp-id": 10125
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
},
{
  "tp-id": "1-25-1",
  "te-tp-id": 12501
  "te": {
    "interface-switching-capability": [
      {
```

```
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  },
  {
    "tp-id": "1-0-28",
    "te-tp-id": 10028
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-28-0",
    "te-tp-id": 12800
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-0-31",
    "te-tp-id": 10031
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  }
}
```

```

    },
    {
      "tp-id": "1-31-0",
      "te-tp-id": 13100
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ]
}

```

A.1.3. Domain 3

```
{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {}
        },
        "network-id": "otn-domain3-abs",
        "provider-id": 203,
        "client-id": 300,
        "te-topology-id": "te-topology:otn-domain3-abs",
        "node": [
          {
            "node-id": "D3",
            "te-node-id": "2.0.3.3",
            "te": {
              "te-node-attributes": {
                "is-abstract": [null],

```

```
"underlay-topology": "domain3-och",
"connectivity-matrices": {
  "is-allowed": true,
  "path-constraints": {
    "bandwidth-generic": {
      "te-bandwidth": {
        "otn": [
          {
            "rate-type": "odul",
            "counter": 2
          }
        ]
      }
    }
  }
}
"connectivity-matrix": [
  {
    "id": 13638,
    "from": "1-0-38",
    "to": "1-38-0"
  },
  {
    "id": 13836,
    "from": "1-0-38",
    "to": "1-36-0"
  },
  {
    "id": 13639,
    "from": "1-0-36",
    "to": "1-39-0"
  },
  {
    "id": 13936,
    "from": "1-0-39",
    "to": "1-36-0"
  },
  {
    "id": 23636,
    "from": "1-0-36",
    "to": "1-36-1"
  },
]
```

```

        {
            "id": 33636,
            "from": "1-1-36",
            "to": "1-36-0"
        },
        {
            "id": 13739,
            "from": "1-0-37",
            "to": "1-39-0"
        },
        {
            "id": 13937,
            "from": "1-0-39",
            "to": "1-37-0"
        },
        {
            "id": 23737,
            "from": "1-0-37",
            "to": "1-37-1"
        },
        {
            "id": 33737,
            "from": "1-1-37",
            "to": "1-37-0"
        }
    ]
}
},
"termination-point": [
    {
        "tp-id": "1-0-36",
        "te-tp-id": 10036
        "te": {
            "interface-switching-capability": [
                {
                    "switching-capability": "switching-otn",
                    "encoding": "lsp-encoding-oduk"
                }
            ]
        }
    }
]
}

```

```
    },
    {
      "tp-id": "1-36-0",
      "te-tp-id": 13600
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ],
  {
    "tp-id": "1-0-37",
    "te-tp-id": 10037
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  }
],
{
  "tp-id": "1-37-0",
  "te-tp-id": 13700
  "te": {
    "interface-switching-capability": [
      {
        "switching-capability": "switching-otn",
        "encoding": "lsp-encoding-oduk"
      }
    ]
  }
}
],
{
  "tp-id": "1-1-37",
  "te-tp-id": 10137
  "te": {
```

```
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      },
    },
    {
      "tp-id": "1-37-1",
      "te-tp-id": 13701
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    },
    {
      "tp-id": "1-0-39",
      "te-tp-id": 10039
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    },
    {
      "tp-id": "1-39-0",
      "te-tp-id": 13900
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ],
}
```

```
    ]
  },
  {
    "tp-id": "1-0-36",
    "te-tp-id": 10036
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-36-0",
    "te-tp-id": 13600
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-0-38",
    "te-tp-id": 10038
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-otn",
          "encoding": "lsp-encoding-oduk"
        }
      ]
    }
  },
  {
    "tp-id": "1-38-0",
```



```
"te-tp-id": 13800
"te": {
  "interface-switching-capability": [
    {
      "switching-capability": "switching-otn",
      "encoding": "lsp-encoding-oduk"
    }
  ]
}
}
```

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Use Cases for SF Aware Topology Models
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Abstract

This document describes some use cases that benefit from the network topology models that are service and network function aware.

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1. Introduction

Normally network connectivity services are discussed as a means to interconnect various abstract or physical network topological elements, such as ports, link termination points and nodes [I-D.ietf-teas-yang-te-topo] [I-D.ietf-teas-yang-te]. However, the connectivity services, strictly speaking, interconnect not the network topology elements per-se, rather, located on/associated with the various network and service functions [RFC7498] [RFC7665]. In many scenarios it is beneficial to decouple the service/network functions from the network topology elements hosting them, describe them in some unambiguous and identifiable way (so that it would be possible, for example, to auto-discover on the network topology service/network functions with identical or similar functionality and characteristics) and engineer the connectivity between the service/network functions, rather than between their current topological locations. The purpose of this document is to describe some use cases that could benefit from such an approach.

2. Exporting SF/NF Information to Network Clients and Other Network SDN Controllers

In the context of Service Function Chain (SFC) orchestration one existing problem is that there is no way to formally describe a Service or Network Function in a standard way (recognizable/understood by a third party) as a resource of a network topology node.

One implication of this is that there is no way for the orchestrator to give a network client even a ball-park idea as to which network's SFs/NFs are available for the client's use/control and where they are located in the network even in terms of abstract topologies/virtual networks configured and managed specifically for the client. Consequently the client has no say on how the SFCs provided for the client by the network should be set up and managed (which SFs are to be used and how they should be chained together, optimized, manipulated, protected, etc.).

Likewise, there is no way for the orchestrator to export SF/NF information to other network controllers. The SFC orchestrator may serve, for example, a higher level controller (such as Network Slicing Orchestrator), with the latter wanting at least some level of control as to which SFs/NFs it wants on its SFCs and how the Service Function Paths (SFPs) are to be routed and provisioned, especially, if it uses services of more than one SFC orchestrator.

The issue of exporting of SF/NF information could be addressed by defining a model, in which formally described/recognizable SF/NF instances are presented as topological elements, for example, hosted by (associated with) TE, L3 or L2 topology nodes. The model could describe whether, how and at what costs the SFs/NFs hosted by a given node could be chained together, how these intra-node SFCs could be connected to the node's Service Function Forwarders (SFFs, entities dealing with SFC NSHs and metadata), and how the SFFs could be connected to the node's Tunnel and Link Termination Points (TTPs and LTPs) to chain the intra-node SFCs across the network topology.

3. Flat End-to-end SFCs Managed on Multi-domain Networks

SFCs may span multiple administrative domains, each of which controlled by a separate SFC controller. The usual solution for such a scenario is the Hierarchical SFCs (H-SFCs), in which the higher level orchestrator controls only SFs located on domain border nodes. Said higher level SFs are chained together into higher level SFCs via lower level (intra-domain) SFCs provisioned and controlled independently by respective domain controllers. The decision as to which higher level SFCs are connected to which lower level SFCs is

driven by packet re-classification every time the packet enters a given domain. Said packet re-classification is very time-consuming operation. Furthermore, the independent nature of higher and lower level SFC control is prone to configuration errors, which may lead to long lasting loops and congestions. It is highly desirable to be able to set up and manage SFCs spanning multiple domains in a flat way as far as the data plane is concerned (i.e. with a single packet classification at the ingress into the multi-domain network but without re-classifications on domain ingress nodes).

One way to achieve this is to have the domain controllers expose SF/NF-aware topologies, and have the higher level orchestrator operate on the network-wide topology, the product of merging of the topologies catered by the domain controllers. This is similar in spirit to setting up, coordinating and managing the transport connectivity (TE tunnels) on a multi-domain multi-vendor transport network.

4. Managing SFCs with TE Constrains

Some SFCs require per SFC link/element and end-to-end TE constrains (bandwidth, delay/jitter, fate sharing/diversity. etc.). Said constraints could be ensured via carrying SFPs inside overlays that are traffic engineered with the constrains in mind. A good analogy would be orchestrating delay constrained L3 VPNs. One way to support such L3 VPNs is to carry MPLS LSPs interconnecting per-VPN VRFs inside delay constrained TE tunnels interconnecting the PEs hosting the VRFs.

Planning, computing and provisioning of TE overlays to constrain arbitrary SFCs, especially those that span multiple administrative domains with each domain controlled by a separate controller, is a very difficult challenge. Currently it is addressed by pre-provisioning on the network of multiple TE tunnels with various TE characteristics, and "nailing down" SFs/NFs to "strategic" locations (e.g. nodes terminating many of such tunnels) in a hope that an adequate set of tunnels could be found to carry the SFP of a given TE-constrained SFC. Such an approach is especially awkward in the case when some or all of the SFs/NFs are VNFs (i.e. could be instantiated at multiple network locations).

SF/NF-aware TE topology model in combination with TE tunnel model will allow for the network orchestrator (or a client controller) to compute, set up and manipulate the TE overlays in the form of TE tunnel chains. Said chains could be dual-optimized compromising on optimal SF/NF locations with optimal TE tunnels interconnecting them. The TE tunnel chains (carrying multiple similarly constrained SFPs)

could be adequately constrained both at individual TE tunnel level and at the chain end-to-end level.

5. SFC Protection and Load Balancing

Currently the combination of TE topology & tunnel models offers to a network controller various capabilities to recover an individual TE tunnel from network failures occurred on one or more network links or transit nodes on the TE paths taken by the TE tunnel's connection(s). However, there is no simple way to recover a TE tunnel from a failure affecting its source or destination node. SF/NF-aware TE topology model can decouple the association of a given SF/NF with its location on the network topology by presenting multiple, identifiable as mutually substitutable SFs/NFs hosted by different TE topology nodes. So, for example, if it is detected that a given TE tunnel destination node is malfunctioning or has gone out of service, the TE tunnel could be re-routed to terminate on a different node hosting functionally the same SFs/NFs as ones hosted by the failed node. This is in line with the ACTN edge migration and function mobility concepts. It is important to note that the described strategy works much better for the stateless SFs/NFs. This is because getting the alternative stateful SFs/NFs into the same respective states as the current (i.e. active, affected by failure) are is a very difficult challenge.

At the SFC level the SF/NF-aware TE topology model can offer SFC dynamic restoration capabilities against failed/malfunctioning SFs/NFs by identifying and provisioning detours to a TE tunnel chain, so that it starts carrying the SFC's SFPs towards healthy SFs/NFs that are functionally the same as the failed ones. Furthermore, multiple parallel TE tunnel chains could be pre-provisioned for the purpose of SFC load balancing and end-to-end protection. In the latter case said parallel TE tunnel chains could be placed to be sufficiently disjoint from each other.

6. Network Clock Synchronization

Many current and future network applications (including 5g and IoT applications) require very accurate time services (PTP level, ns resolution). One way to implement the adequate network clock synchronization for such services is via describing network clocks as NFs on an NF-aware TE topology optimized to have best possible delay variation characteristics. Because such a topology will contain delay/delay variation metrics of topology links and node cross-connects, as well as costs in terms of delay/delay variation of connecting clocks to hosting them node link and tunnel termination points, it will be possible to dynamically select and provision bi-directional time-constrained deterministic paths or trees connecting

clocks (e.g. grand master and boundary clocks) for the purpose of exchange of clock synchronization information. Note that network clock aware TE topologies separately provided by domain controllers will enable multi-domain network orchestrator to set up and manipulate the clock synchronization paths/trees spanning multiple network domains.

7. Client - Provider Network Slicing Interface

3GPP defines network slice as "a set of network functions and the resources for these network functions which are arranged and configured, forming a complete logical network to meet certain network characteristics.". Network slice could be also defined as a logical partition of a provider's network that is owned and managed by a tenant. SF/NF-aware TE topology model has a potential to support a very important interface between network slicing clients and providers because, on the one hand, the model can describe holistically and hierarchically the client's requirements and preferences with respect to a network slice functional, topological and traffic engineering aspects, as well as of the degree of resource separation/ sharing between the slices, thus allowing for the client (up to agreed upon extent) to dynamically (re-)configure the slice or (re-)schedule said (re-)configurations in time, while, on the other hand, allowing for the provider to convey to the client the slice's operational state information and telemetry the client has expressed interest in.

8. Dynamic Assignment of Regenerators for L0 Services

On large optical networks some of provided to their clients L0 services could not be provisioned as single Och trails, rather, as chains of such trails interconnected via regenerators, such as 3R regenerators. Current practice of the provisioning of such services requires configuration of explicit paths (EROs) describing identity and location of regenerators to be used. A solution is highly desirable that could:

- o Identify such services based, for example, on optical impairment computations;
- o Assign adequate for the services regenerators dynamically out of the regenerators that are grouped together in pools and strategically scattered over the network topology nodes;
- o Compute and provision supporting the services chains of optical trails interconnected via so selected regenerators, optimizing the chains to use minimal number of regenerators, their optimal

locations, as well as optimality of optical paths interconnecting them;

- o Ensure recovery of such chains from any failures that could happen on links, nodes or regenerators along the chain path.

NF-aware TE topology model (in this case L1 NF-aware L0 topology model) is just the model that could provide a network controller (or even a client controller operating on abstract NF-aware topologies provided by the network) to realize described above computations and orchestrate the service provisioning and network failure recovery operations.

9. Dynamic Assignment of OAM Functions for L1 Services

OAM functionality is normally managed by configuring and manipulating TCM/MEP functions on network ports terminating connections or their segments over which OAM operations, such as performance monitoring, are required to be performed. In some layer networks (e.g. Ethernet) said TCMS/MEPs could be configured on any network ports. In others (e.g. OTN/ODUk) the TCMS/MEPs could be configured on some (but not all network ports) due to the fact that the OAM functionality (i.e. recognizing and processing of OAM messages, supporting OAM protocols and FSMs) requires in these layer networks certain support in the data plane, which is not available on all network nodes. This makes TCMS/MEPs good candidates to be modeled as NFs. This also makes TCM/MEP aware topology model a good basis for placing dynamically an ODUk connection to pass through optimal OAM locations without mandating the client to specify said locations explicitly.

10. SFC Abstraction and Scaling

SF/NF-aware topology may contain information on native SFs/NFs (i.e. SFs/NFs as known to the provider itself) and/or abstract SFs/NFs (i.e. logical/macro SFs/NFs representing one or more SFCs each made of native and/or lower level abstract SFs/NFs). As in the case of abstracting topology nodes, abstracting SFs/NFs is hierarchical in nature - the higher level of SF/NF-aware topology, the "larger" abstract SFs/NFs are, i.e. the larger data plane SFCs they represent. This allows for managing large scale networks with great number of SFs/NFs (such as Data Center interconnects) in a hierarchical, highly scalable manner resulting in control of very large number of flat in the data plane SFCs that span multiple domains.

11. Dynamic Compute/VM/Storage Resource Assignment

In a distributed data center networks, virtual machines for compute resources may need to be dynamically re-allocated due to various reasons such as DCI network failure, compute resource load balancing, etc. In many cases, the DCI connectivity for the source and the destination is not predetermined. There may be a pool of sources and a pool of destination data centers associated with re-allocation of compute/VM/storage resources. There is no good mechanism to date to capture this dynamicity nature of compute/VM/storage resource reallocation. Generic Compute/VM/Storage resources can be described and announced as a SF where a DC hosting these resources can be modeled as an abstract node. Topology interconnecting these abstract nodes (DCs) in general is of multi-domain nature. Thus, SF-aware topology model can facilitate a joint optimization of TE network resources and Compute/VM/Storage resources and solve Compute/VM/Storage mobility problem within and between DCs.

12. IANA Considerations

This document has no actions for IANA.

13. Security Considerations

This document does not define networking protocols and data, hence are not directly responsible for security risks.

14. Acknowledgements

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Abstract

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based protocols (e.g., NETCONF or RESTCONF).

This document describes some use cases where a path computation request, via YANG-based protocols (e.g., NETCONF or RESTCONF), can be needed.

This document also proposes a yang model for a stateless RPC which complements the stateful solution defined in [TE-TUNNEL].

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1. Introduction

There are scenarios, typically in a hierarchical SDN context, in which an orchestrator may not have detailed information to be able to perform an end-to-end path computation and would need to request lower layer/domain controllers to calculate some (partial) feasible paths.

When we are thinking to this type of scenarios we have in mind specific level of interfaces on which this request can be applied.

We can reference ABNO Control Interface [RFC7491] in which an Application Service Coordinator can request ABNO controller to take in charge path calculation (see Figure 1 in the RFC) and/or ACTN [ACTN-frame], where controller hierarchy is defined, the need for path computation arises on both interfaces CMI (interface between Customer Network Controller(CNC) and Multi Domain Service Coordinator (MDSC)) and/or MPI (interface between MSDC-PNC).[ACTN-

Info] describes an information model for the Path Computation request.

Multiple protocol solutions can be used for communication between different controller hierarchical levels. This document assumes that the controllers are communicating using YANG-based protocols (e.g., NETCONF or RESTCONF).

Path Computation Elements, Controllers and Orchestrators perform their operations based on Traffic Engineering Databases (TED). Such TEDs can be described, in a technology agnostic way, with the YANG Data Model for TE Topologies [TE-TOPO]. Furthermore, the technology specific details of the TED are modeled in the augmented TE topology models (e.g. [L1-TOPO] for Layer-1 ODU technologies).

The availability of such topology models allows providing the TED using YANG-based protocols (e.g., NETCONF or RESTCONF). Furthermore, it enables a PCE/Controller performing the necessary abstractions or modifications and offering this customized topology to another PCE/Controller or high level orchestrator.

The tunnels that can be provided over the networks described with the topology models can be also set-up, deleted and modified via YANG-based protocols (e.g., NETCONF or RESTCONF) using the TE-Tunnel Yang model [TE-TUNNEL].

This document describes some use cases where a path computation request, via YANG-based protocols (e.g., NETCONF or RESTCONF), can be needed.

This document also proposes a yang model for a stateless RPC which complements the stateful solution defined in [TE-TUNNEL].

2. Use Cases

This section presents different use cases, where an orchestrator needs to request underlying SDN controllers for path computation.

The presented use cases have been grouped, depending on the different underlying topologies: a) IP-Optical integration; b) Multi-domain Traffic Engineered (TE) Networks; and c) Data center interconnections.

2.1. IP-Optical integration

In these use cases, an Optical domain is used to provide connectivity between IP routers which are connected with the Optical domains using access links (see Figure 1).

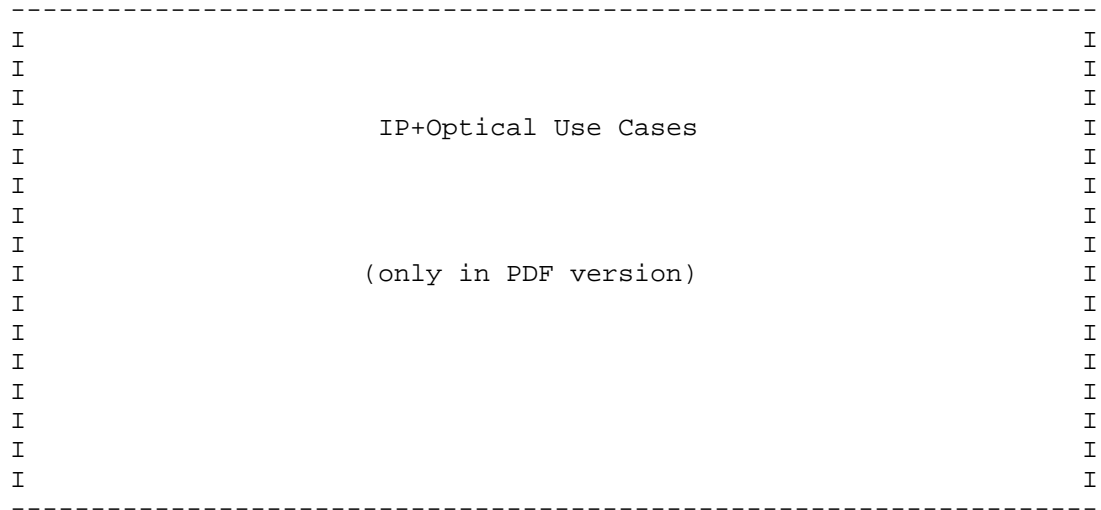


Figure 1 - IP+Optical Use Cases

It is assumed that the Optical domain controller provides to the orchestrator an abstracted view of the Optical network. A possible abstraction shall be representing the optical domain as one "virtual node" with "virtual ports" connected to the access links.

The path computation request helps the orchestrator to know which are the real connections that can be provided at the optical domain.

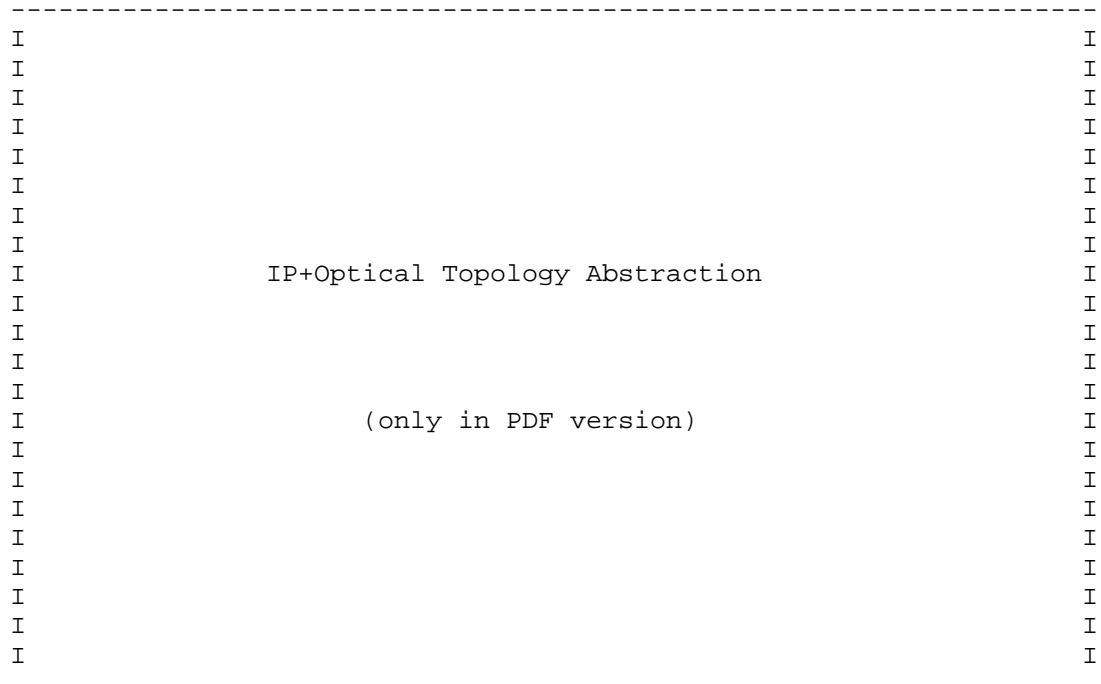


Figure 2 - IP+Optical Topology Abstraction

2.1.1.1. Inter-layer path computation

In this use case, the orchestrator needs to setup an optimal path between two IP routers R1 and R2.

As depicted in Figure 2, the Orchestrator has only an "abstracted view" of the physical network, and it does not know the feasibility or the cost of the possible optical paths (e.g., VP1-VP4 and VP2-VP5), which depend from the current status of the physical resources within the optical network and on vendor-specific optical attributes.

The orchestrator can request the underlying Optical domain controller to compute a set of potential optimal paths, taking into account optical constraints. Then, based on its own constraints, policy and knowledge (e.g. cost of the access links), it can choose

which one of these potential paths to use to setup the optimal e2e path crossing optical network.

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Figure 3 - IP+Optical Path Computation Example

For example, in Figure 3, the Orchestrator can request the Optical domain controller to compute the paths between VP1-VP4 and VP2-VP5 and then decide to setup the optimal end-to-end path using the VP2-VP5 Optical path even this is not the optimal path from the Optical domain perspective.

Considering the dynamicity of the connectivity constraints of an Optical domain, it is possible that a path computed by the Optical domain controller when requested by the Orchestrator is no longer valid when the Orchestrator requests it to be setup up.

It is worth noting that with the approach proposed in this document, the likelihood for this issue to happen can be quite small since the time window between the path computation request and the path setup request should be quite short (especially if compared with the time that would be needed to update the information of a very detailed abstract connectivity matrix).

If this risk is still not acceptable, the Orchestrator may also optionally request the Optical domain controller not only to compute the path but also to keep track of its resources (e.g., these resources can be reserved to avoid being used by any other connection). In this case, some mechanism (e.g., a timeout) needs to be defined to avoid having stranded resources within the Optical domain.

These issues and solutions can be fine-tuned during the design of the YANG model for requesting Path Computation.

2.1.2. Route Diverse IP Services

This is for further study.

2.2. Multi-domain TE Networks

In this use case there are two TE domains which are interconnected together by multiple inter-domains links.

A possible example could be a multi-domain optical network.

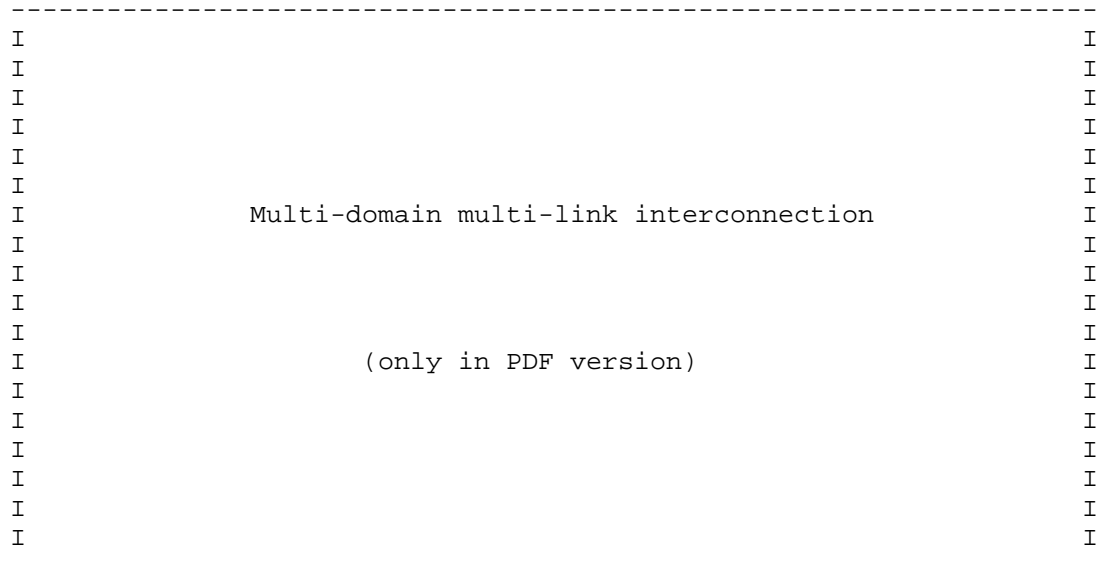


Figure 4 - Multi-domain multi-link interconnection

In order to setup an end-to-end multi-domain TEpath (e.g., between nodes A and H), the orchestrator needs to know the feasibility or the cost of the possible TE paths within the two TE domains, which depend from the current status of the physical resources within each TE network. This is more challenging in case of optical networks because the optimal paths depend also on vendor-specific optical attributes (which may be different in the two domains if they are provided by different vendors).

In order to setup a multi-domain TE path (e.g., between nodes A and H), Orchestrator can request the TE domain controllers to compute a set of intra-domain optimal paths and take decisions based on the information received. For example:

- o The Orchestrator asks TE domain controllers to provide set of paths between A-C, A-D, E-H and F-H
- o TE domain controllers return a set of feasible paths with the associated costs: the path A-C is not part of this set (in optical networks, it is typical to have some paths not being feasible due to optical constraints that are known only by the optical domain controller)
- o The Orchestrator will select the path A- D-F- H since it is the only feasible multi-domain path and then request the TE domain controllers to setup the A-D and F-H intra-domain paths
- o If there are multiple feasible paths, the Orchestrator can select the optimal path knowing the cost of the intra-domain paths (provided by the TE domain controllers) and the cost of the inter-domain links (known by the Orchestrator)

This approach may have some scalability issues when the number of TE domains is quite big (e.g. 20).

In this case, it would be worthwhile using the abstract TE topology information provided by the domain controllers to limit the number of potential optimal end-to-end paths and then request path computation to fewer domain controllers in order to decide what the optimal path within this limited set is.

For more details, see section 3.3.

2.3. Data center interconnections

In these use case, there is an TE domain which is used to provide connectivity between data centers which are connected with the TE domain using access links.

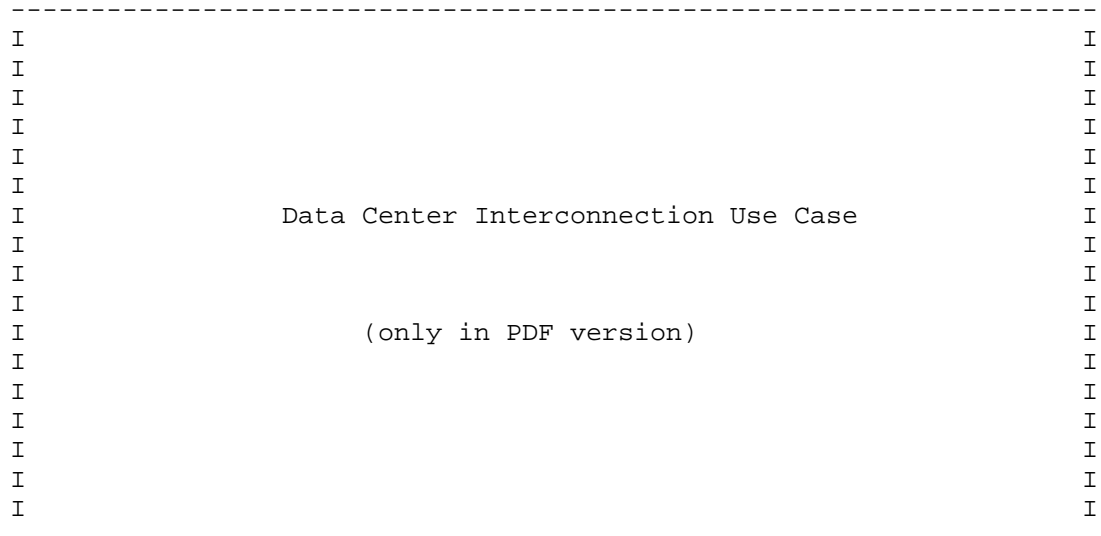


Figure 5 - Data Center Interconnection Use Case

In this use case, a virtual machine within Data Center 1 (DC1) needs to transfer data to another virtual machine that can reside either in DC2 or in DC3.

The optimal decision depends both on the cost of the TE path (DC1-DC2 or DC1-DC3) and of the computing power (data center resources) within DC2 or DC3.

The Cloud Orchestrator may not be able to make this decision because it has only an abstract view of the TE network (as in use case in 2.1).

The cloud orchestrator can request to the TE domain controller to compute the cost of the possible TE paths (e.g., DC1-DC2 and DC1-DC3) and to the DC controller to compute the cost of the computing power (DC resources) within DC2 and DC3 and then it can take the decision about the optimal solution based on this information and its policy.

3. Interactions with TE Topology

The use cases described in section 2 have been described assuming that the topology view exported by each underlying SDN controller to the orchestrator is aggregated using the "virtual node model", defined in [RFC7926].

TE Topology information, e.g., as provided by [TE-TOPO], could in theory be used by an underlying SDN controllers to provide TE information to the orchestrator thus allowing the Path Computation Element (PCE) within the Orchestrator to perform multi-domain path computation by its own, without requesting path computations to the underlying SDN controllers.

This section analyzes the need for an orchestrator to request underlying SDN controllers for path computation even in these scenarios as well as how the TE Topology information and the path computation can be complementary.

In nutshell, there is a scalability trade-off between providing all the TE information needed by the Orchestrator's PCE to take optimal path computation decisions by its own versus requesting the Orchestrator to ask to too many underlying SDN Domain Controllers a set of feasible optimal intra-domain TE paths.

3.1. TE Topology Aggregation using the "virtual link model"

Using the TE Topology model, as defined in [TE-TOPO], the underlying SDN controller can export the whole TE domain as a single abstract TE node with a "detailed connectivity matrix", which extends the "connectivity matrix", defined in [RFC7446], with specific TE attributes (e.g., delay, SRLGs and summary TE metrics).

The information provided by the "detailed abstract connectivity matrix" would be equivalent to the information that should be provided by "virtual link model" as defined in [RFC7926].

For example, in the IP-Optical integration use case, described in section 2.1, the Optical domain controller can make the information shown in Figure 3 available to the Orchestrator as part of the TE Topology information and the Orchestrator could use this information to calculate by its own the optimal path between routers R1 and R2, without requesting any additional information to the Optical Domain Controller.

However, there is a tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and scalability to be considered when designing the amount of information to provide within the "detailed abstract connectivity matrix".

Figure 6 below shows another example, similar to Figure 3, where there are two possible Optical paths between VP1 and VP4 with different properties (e.g., available bandwidth and cost).

```

-----
I                                     I
I           IP+Optical Path Computation Example           I
I               with multiple choices                       I
I                                                         I
I                                                         I
I                                                         I
I               (only in PDF version)                       I
I                                                         I
I                                                         I
-----

```

Figure 6 - IP+Optical Path Computation Example with multiple choices

Reporting all the information, as in Figure 6, using the "detailed abstract connectivity matrix", is quite challenging from a scalability perspective. The amount of this information is not just based on number of end points (which would scale as N-square), but also on many other parameters, including client rate, user constraints / policies for the service, e.g. max latency < N ms, max cost, etc., exclusion policies to route around busy links, min OSNR margin, max preFEC BER etc. All these constraints could be different based on connectivity requirements.

In the following table, a list of the possible constraints, associated with their potential cardinality, is reported.

The maximum number of potential connections to be computed and reported is, in first approximation, the multiplication of all of them.

Constraint Cardinality

End points $N(N-1)/2$ if connections are bidirectional (OTN and WDM),
 $N(N-1)$ for unidirectional connections.

Bandwidth In WDM networks, bandwidth values are expressed in GHz.

On fixed-grid WDM networks, the central frequencies are on a 50GHz grid and the channel width of the transmitters are typically 50GHz such that each central frequency can be used, i.e., adjacent channels can be placed next to each other in terms of central frequencies.

On flex-grid WDM networks, the central frequencies are on a 6.25GHz grid and the channel width of the transmitters can be multiples of 12.5GHz.

For fixed-grid WDM networks typically there is only one possible bandwidth value (i.e., 50GHz) while for flex-grid WDM networks typically there are 4 possible bandwidth values (e.g., 37.5GHz, 50GHz, 62.5GHz, 75GHz).

In OTN (ODU) networks, bandwidth values are expressed as pairs of ODU type and, in case of ODUFlex, ODU rate in bytes/sec as described in section 5 of [RFC7139].

For "fixed" ODUk types, 6 possible bandwidth values are possible (i.e., ODU0, ODU1, ODU2, ODU2e, ODU3, ODU4).

For ODUFlex(GFP), up to 80 different bandwidth values can be specified, as defined in Table 7-8 of [ITU-T G.709-2016].

For other ODUFlex types, like ODUFlex(CBR), the number of possible bandwidth values depends on the rates of the clients that could be mapped over these ODUFlex types, as shown in Table 7.2 of [ITU-T G.709-2016], which in theory could be a continuum of values. However, since different ODUFlex bandwidths that use the same number of TSS on each link along the path are equivalent for path computation purposes, up to 120 different bandwidth ranges can be specified.

Ideas to reduce the number of ODUFlex bandwidth values in the detailed connectivity matrix, to less than 100, are for further study.

Bandwidth specification for ODUCn is currently for further study but it is expected that other bandwidth values can be specified as integer multiples of 100Gb/s.

In IP we have bandwidth values in bytes/sec. In principle, this is a countinuum of values, but in practice we can identify a set of bandwidth ranges, where any bandwidth value inside the same range produces the same path.

The number of such ranges is the cardinality, which depends on the topology, available bandwidth and status of the network. Simulations (Note: reference paper submitted for publication) show that values for medium size topologies (around 50-150 nodes) are in the range 4-7 (5 on average) for each end points couple.

Metrics IGP, TE and hop number are the basic objective metrics defined so far. There are also the 2 objective functions defined in [RFC5541]: Minimum Load Path (MLP) and Maximum Residual Bandwidth Path (MBP). Assuming that one only metric or objective function can be optimized at once, the total cardinality here is 5.

With [PCEP-Service-Aware], a number of additional metrics are defined, including Path Delay metric, Path Delay Variation metric and Path Loss metric, both for point-to-point and point-to-multipoint paths. This increases the cardinality to 8.

Bounds Each metric can be associated with a bound in order to find a path having a total value of that metric lower than the given bound. This has a potentially very high cardinality (as any value for the bound is allowed). In practice there is a maximum value of the bound (the one with the maximum value of the associated metric) which results always in the same path, and a range approach like for bandwidth in IP should produce also in this case the cardinality. Assuming to have a cardinality similar to the one of the bandwidth (let say 5 on average) we should have 6 (IGP, TE, hop, path delay, path delay variation and path loss; we don't consider here the two

objective functions of [RFC5541] as they are conceived only for optimization)*5 = 30 cardinality.

Priority We have 8 values for setup priority, which is used in path computation to route a path using free resources and, where no free resources are available, resources used by LSPs having a lower holding priority.

Local prot It's possible to ask for a local protected service, where all the links used by the path are protected with fast reroute (this is only for IP networks, but line protection schemas are available on the other technologies as well). This adds an alternative path computation, so the cardinality of this constraint is 2.

Administrative

Colors Administrative colors (aka affinities) are typically assigned to links but when topology abstraction is used affinity information can also appear in the detailed connectivity matrix.

There are 32 bits available for the affinities. Links can be tagged with any combination of these bits, and path computation can be constrained to include or exclude any or all of them. The relevant cardinality is 3 (include-any, exclude-any, include-all) times 2^{32} possible values. However, the number of possible values used in real networks is quite small.

Included Resources

A path computation request can be associated to an ordered set of network resources (links, nodes) to be included along the computed path. This constraint would have a huge cardinality as in principle any combination of network resources is possible. However, as far as the Orchestrator doesn't know details about the internal topology of the domain, it shouldn't include this type of constraint at all (see more details below).

Excluded Resources

A path computation request can be associated to a set of network resources (links, nodes, SRLGs) to be excluded from the computed path. Like for included resources,

this constraint has a potentially very high cardinality, but, once again, it can't be actually used by the Orchestrator, if it's not aware of the domain topology (see more details below).

As discussed above, the Orchestrator can specify include or exclude resources depending on the abstract topology information that the domain controller exposes:

- o In case the domain controller exposes the entire domain as a single abstract TE node with his own external terminations and connectivity matrix (whose size we are estimating), no other topological details are available, therefore the size of the connectivity matrix only depends on the combination of the constraints that the Orchestrator can use in a path computation request to the domain controller. These constraints cannot refer to any details of the internal topology of the domain, as those details are not known to the Orchestrator and so they do not impact size of connectivity matrix exported.
- o Instead in case the domain controller exposes a topology including more than one abstract TE nodes and TE links, and their attributes (e.g. SRLGs, affinities for the links), the Orchestrator knows these details and therefore could compute a path across the domain referring to them in the constraints. The connectivity matrixes to be estimated here are the ones relevant to the abstract TE nodes exported to the Orchestrator. These connectivity matrixes and therefore their sizes, while cannot depend on the other abstract TE nodes and TE links, which are external to the given abstract node, could depend to SRLGs (and other attributes, like affinities) which could be present also in the portion of the topology represented by the abstract nodes, and therefore contribute to the size of the related connectivity matrix.

We also don't consider here the possibility to ask for more than one path in diversity or for point-to-multi-point paths, which are for further study.

Considering for example an IP domain without considering SRLG and affinities, we have an estimated number of paths depending on these estimated cardinalities:

Endpoints = $N*(N-1)$, Bandwidth = 5, Metrics = 6, Bounds = 20,
Priority = 8, Local prot = 2

The number of paths to be pre-computed by each IP domain is therefore $24960 * N(N-1)$ where N is the number of domain access points.

This means that with just 4 access points we have nearly 300000 paths to compute, advertise and maintain (if a change happens in the domain, due to a fault, or just the deployment of new traffic, a substantial number of paths need to be recomputed and the relevant changes advertised to the upper controller).

This seems quite challenging. In fact, if we assume a mean length of 1K for the json describing a path (a quite conservative estimate), reporting 300000 paths means transferring and then parsing more than 300 Mbytes for each domain. If we assume that 20% (to be checked) of this paths change when a new deployment of traffic occurs, we have 60 Mbytes of transfer for each domain traversed by a new end-to-end path. If a network has, let say, 20 domains (we want to estimate the load for a non-trivial domain setup) in the beginning a total initial transfer of 6Gigs is needed, and eventually, assuming 4-5 domains are involved in mean during a path deployment we could have 240-300 Mbytes of changes advertised to the higher order controller.

Further bare-bone solutions can be investigated, removing some more options, if this is considered not acceptable; in conclusion, it seems that an approach based only on connectivity matrix is hardly feasible, and could be applicable only to small networks with a limited meshing degree between domains and renouncing to a number of path computation features.

It is also worth noting that the "connectivity matrix" has been originally defined in WSON, [RFC7446] to report the connectivity constraints of a physical node within the WDM network: the information it contains is pretty "static" and therefore, once taken and stored in the TE data base, it can be always being considered valid and up-to-date in path computation request.

Using the "connectivity matrix" with an abstract node to abstract the information regarding the connectivity constraints of an Optical domain, would make this information more "dynamic" since the connectivity constraints of an Optical domain can change over time because some optical paths that are feasible at a given time may become unfeasible at a later time when e.g., another optical path is established. The information in the "detailed abstract connectivity matrix" is even more dynamic since the establishment of another optical path may change some of the parameters (e.g., delay or

available bandwidth) in the "detailed abstract connectivity matrix" while not changing the feasibility of the path.

"Connectivity matrix" is sometimes confused with optical reach table that contain multiple (e.g. k-shortest) regen-free reachable paths for every A-Z node combination in the network. Optical reach tables can be calculated offline, utilizing vendor optical design and planning tools, and periodically uploaded to the Controller: these optical path reach tables are fairly static. However, to get the connectivity matrix, between any two sites, either a regen free path can be used, if one is available, or multiple regen free paths are concatenated to get from src to dest, which can be a very large combination. Additionally, when the optical path within optical domain needs to be computed, it can result in different paths based on input objective, constraints, and network conditions. In summary, even though "optical reachability table" is fairly static, which regen free paths to build the connectivity matrix between any source and destination is very dynamic, and is done using very sophisticated routing algorithms.

There is therefore the need to keep the information in the "connectivity matrix" updated which means that there another tradeoff between the accuracy (i.e., providing "all" the information that might be needed by the Orchestrator's PCE) and having up-to-date information. The more the information is provided and the longer it takes to keep it up-to-date which increases the likelihood that the Orchestrator's PCE computes paths using not updated information.

It seems therefore quite challenging to have a "detailed abstract connectivity matrix" that provides accurate, scalable and updated information to allow the Orchestrator's PCE to take optimal decisions by its own.

If the information in the "detailed abstract connectivity matrix" is not complete/accurate, we can have the following drawbacks considering for example the case in Figure 6:

- o If only the VP1-VP4 path with available bandwidth of 2 Gb/s and cost 50 is reported, the Orchestrator's PCE will fail to compute a 5 Gb/s path between routers R1 and R2, although this would be feasible;

- o If only the VP1-VP4 path with available bandwidth of 10 Gb/s and cost 60 is reported, the Orchestrator's PCE will compute, as optimal, the 1 Gb/s path between R1 and R2 going through the VP2-VP5 path within the Optical domain while the optimal path would actually be the one going through the VP1-VP4 sub-path (with cost 50) within the Optical domain.

Instead, using the approach proposed in this document, the Orchestrator, when it needs to setup an end-to-end path, it can request the Optical domain controller to compute a set of optimal paths (e.g., for VP1-VP4 and VP2-VP5) and take decisions based on the information received:

- o When setting up a 5 Gb/s path between routers R1 and R2, the Optical domain controller may report only the VP1-VP4 path as the only feasible path: the Orchestrator can successfully setup the end-to-end path passing through this Optical path;
- o When setting up a 1 Gb/s path between routers R1 and R2, the Optical domain controller (knowing that the path requires only 1 Gb/s) can report both the VP1-VP4 path, with cost 50, and the VP2-VP5 path, with cost 65. The Orchestrator can then compute the optimal path which is passing through the VP1-VP4 sub-path (with cost 50) within the Optical domain.

3.2. TE Topology Abstraction

Using the TE Topology model, as defined in [TE-TOP0], the underlying SDN controller can export an abstract TE Topology, composed by a set of TE nodes and TE links, which are abstracting the topology controlled by each domain controller.

Considering the example in Figure 4, the TE domain controller 1 can export a TE Topology encompassing the TE nodes A, B, C and D and the TE Link interconnecting them. In a similar way, TE domain controller 2 can export a TE Topology encompassing the TE nodes E, F, G and H and the TE Link interconnecting them.

In this example, for simplicity reasons, each abstract TE node maps with each physical node, but this is not necessary.

In order to setup a multi-domain TE path (e.g., between nodes A and H), the Orchestrator can compute by its own an optimal end-to-end path based on the abstract TE topology information provided by the domain controllers. For example:

- o Orchestrator's PCE, based on its own information, can compute the optimal multi-domain path being A-B-C-E-G-H, and then request the TE domain controllers to setup the A-B-C and E-G-H intra-domain paths
- o But, during path setup, the domain controller may find out that A-B-C intra-domain path is not feasible (as discussed in section 2.2, in optical networks it is typical to have some paths not being feasible due to optical constraints that are known only by the optical domain controller), while only the path A-B-D is feasible
- o So what the hierarchical controller computed is not good and need to re-start the path computation from scratch

As discussed in section 3.1, providing more extensive abstract information from the TE domain controllers to the multi-domain Orchestrator may lead to scalability problems.

In a sense this is similar to the problem of routing and wavelength assignment within an Optical domain. It is possible to do first routing (step 1) and then wavelength assignment (step 2), but the chances of ending up with a good path is low. Alternatively, it is possible to do combined routing and wavelength assignment, which is known to be a more optimal and effective way for Optical path setup. Similarly, it is possible to first compute an abstract end-to-end path within the multi-domain Orchestrator (step 1) and then compute an intra-domain path within each Optical domain (step 2), but there are more chances not to find a path or to get a suboptimal path that performing per-domain path computation and then stitch them.

3.3. Complementary use of TE topology and path computation

As discussed in section 2.2, there are some scalability issues with path computation requests in a multi-domain TE network with many TE domains, in terms of the number of requests to send to the TE domain controllers. It would therefore be worthwhile using the TE topology information provided by the domain controllers to limit the number of requests.

An example can be described considering the multi-domain abstract topology shown in Figure 7. In this example, an end-to-end TE path between domains A and F needs to be setup. The transit domain should be selected between domains B, C, D and E.

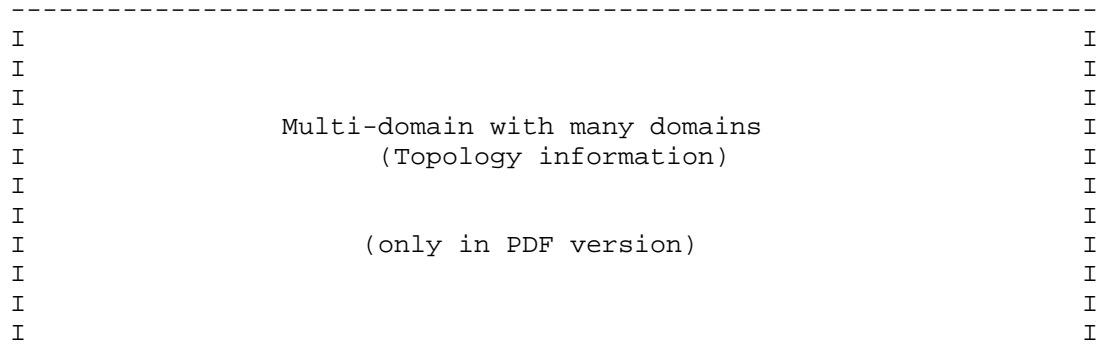


Figure 7 - Multi-domain with many domains (Topology information)

The actual cost of each intra-domain path is not known a priori from the abstract topology information. The Orchestrator only knows, from the TE topology provided by the underlying domain controllers, the feasibility of some intra-domain paths and some upper-bound and/or lower-bound cost information. With this information, together with the cost of inter-domain links, the Orchestrator can understand by its own that:

- o Domain B cannot be selected as the path connecting domains A and E is not feasible;
- o Domain E cannot be selected as a transit domain since it is known from the abstract topology information provided by domain controllers that the cost of the multi-domain path A-E-F (which is 100, in the best case) will be always be higher than the cost of the multi-domain paths A-D-F (which is 90, in the worst case) and A-E-F (which is 80, in the worst case)

Therefore, the Orchestrator can understand by its own that the optimal multi-domain path could be either A-D-F or A-E-F but it cannot know which one of the two possible options actually provides the optimal end-to-end path.

The Orchestrator can therefore request path computation only to the TE domain controllers A, D, E and F (and not to all the possible TE domain controllers).

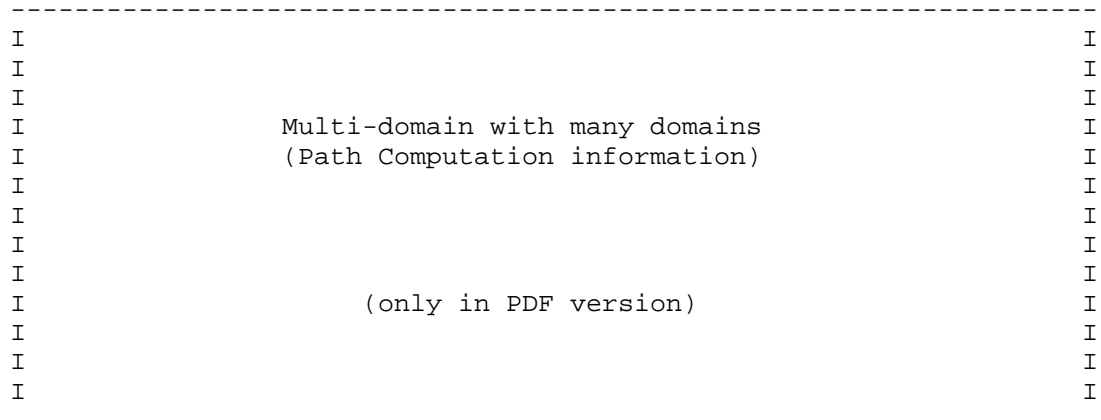


Figure 8 - Multi-domain with many domains (Path Computation information)

Based on these requests, the Orchestrator can know the actual cost of each intra-domain paths which belongs to potential optimal end-to-end paths, as shown in Figure 8, and then compute the optimal end-to-end path (e.g., A-D-F, having total cost of 50, instead of A-C-F having a total cost of 70).

4. Motivation for a YANG Model

4.1. Benefits of common data models

Path computation requests should be closely aligned with the YANG data models that provide (abstract) TE topology information, i.e., [TE-TOPO] as well as that are used to configure and manage TE Tunnels, i.e., [TE-TUNNEL]. Otherwise, an error-prone mapping or correlation of information would be required. For instance, there is benefit in using the same endpoint identifiers in path computation requests and in the topology modeling. Also, the attributes used in path computation constraints could use the same or similar data models. As a result, there are many benefits in aligning path computation requests with YANG models for TE topology information and TE Tunnels configuration and management.

4.2. Benefits of a single interface

A typical use case for path computation requests is the interface between an orchestrator and a domain controller. The system integration effort is typically lower if a single, consistent interface is used between such systems, i.e., one data modeling language (i.e., YANG) and a common protocol (e.g., NETCONF or RESTCONF).

Practical benefits of using a single, consistent interface include:

1. Simple authentication and authorization: The interface between different components has to be secured. If different protocols have different security mechanisms, ensuring a common access control model may result in overhead. For instance, there may be a need to deal with different security mechanisms, e.g., different credentials or keys. This can result in increased integration effort.
2. Consistency: Keeping data consistent over multiple different interfaces or protocols is not trivial. For instance, the sequence of actions can matter in certain use cases, or transaction semantics could be desired. While ensuring consistency within one protocol can already be challenging, it is typically cumbersome to achieve that across different protocols.
3. Testing: System integration requires comprehensive testing, including corner cases. The more different technologies are involved, the more difficult it is to run comprehensive test cases and ensure proper integration.
4. Middle-box friendliness: Provider and consumer of path computation requests may be located in different networks, and middle-boxes such as firewalls, NATs, or load balancers may be deployed. In such environments it is simpler to deploy a single protocol. Also, it may be easier to debug connectivity problems.
5. Tooling reuse: Implementers may want to implement path computation requests with tools and libraries that already exist in controllers and/or orchestrators, e.g., leveraging the rapidly growing eco-system for YANG tooling.

4.3. Extensibility

Path computation is only a subset of the typical functionality of a controller. In many use cases, issuing path computation requests comes along with the need to access other functionality on the same

system. In addition to obtaining TE topology, for instance also configuration of services (setup/modification/deletion) may be required, as well as:

1. Receiving notifications for topology changes as well as integration with fault management
2. Performance management such as retrieving monitoring and telemetry data
3. Service assurance, e.g., by triggering OAM functionality
4. Other fulfilment and provisioning actions beyond tunnels and services, such as changing QoS configurations

YANG is a very extensible and flexible data modeling language that can be used for all these use cases.

Adding support for path computation requests to YANG models would seamlessly complement with [TE-TOPO] and [TE-TUNNEL] in the use cases where YANG-based protocols (e.g., NETCONF or RESTCONF) are used.

5. Path Computation for multiple LSPs

There are use cases, where path computation is required for multiple Traffic Engineering Label Switched Paths (TE LSPs) through a network or through a network domain. It may be advantageous to request the new paths for a set of LSPs in one single path computation request [RFC5440] that also includes information regarding the desired objective function, see [RFC5541].

In the context of abstraction and control of TE networks (ACTN), as defined in [ACTN-Frame], when a MDSC receives a virtual network (VN) request from a CNC, the MDSC needs to perform path computation for multiple LSPs as a typical VN is constructed by a set of multiple paths also called end-to-end tunnels. The MDSC may send a single path computation request to the PNC for multiple LSPs, i.e. between the VN end points (access points in ACTN terminology).

In a more general context, when a MDSC needs to send multiple path provisioning requests to the PNC, the MDSC may also group these path provisioning requests together and send them in a single message to the PNC instead of sending separate requests for each path.

6. YANG Model for requesting Path Computation

The TE Tunnel YANG model has been extended to support the need to request path computation.

It is possible to request path computation by configuring a "compute-only" TE tunnel and retrieving the computed path(s) in the LSP(s) Record-Route Object (RRO) list as described in section 3.3.1 of [TE-TUNNEL].

This is a stateful solution since the state of each created "compute-only" TE tunnel needs to be maintained and updated, when underlying network conditions change.

The need also for a stateless solution, based on an RPC, has been recognized, as outlined in section 6.1.

A proposal for a stateless RPC to request path computation is provided in section 6.2.

6.1. Stateless and Stateful Path Computation

It is very useful to provide options for both stateless and stateful path computation mechanisms. It is suggested to use stateless mechanisms as much as possible and to rely on stateful path computation when really needed.

Stateless RPC allows requesting path computation using a simple atomic operation and it is the natural option/choice, especially with stateless PCE.

Since the operation is stateless, there is no guarantee that the returned path would still be available when path setup is requested: this is not a major issue in case the time between path computation and path setup is short.

The RPC response must be provided synchronously and, if collaborative computations are time consuming, it may not be possible to immediate reply to client.

In this case, the client can define a maximum time it can wait for the reply, such that if the computation does not complete in time, the server will abort the path computation and reply to the client with an error. It may be possible that the server has tighter timing

constraints than the client: in this case the path computation is aborted earlier than the time specified by the client.

Note - The RPC response issue (slow RPC server) is not specific to the path computation RPC case so, it may be worthwhile, evaluating whether a more generic solution applicable to any YANG RPC can be used instead.

In case the stateless solution is not sufficient, a stateful solution, based on "compute-only" TE tunnel, could be used to support asynchronous operations and/or to get notifications in case the computed path has been changed.

It is worth noting that also the stateful solution, although increasing the likelihood that the computed path is available at path setup, it does not guaranteed that because notifications may not be reliable or delivered on time.

The stateful path computation has also the following drawbacks:

- o Several messages required for any path computation
- o Requires persistent storage in the provider controller
- o Need for garbage collection for stranded paths
- o Process burden to detect changes on the computed paths in order to provide notifications update

6.2. YANG model for stateless TE path computation

6.2.1. YANG Tree

Figure 9 below shows the tree diagram of the YANG model defined in module ietf-te-path-computation.yang.

```

module: ietf-te-path-computation
  +--rw paths
  |   +--ro path* [path-id]
  |   |   +--ro _telink* [link-ref]
  |   |   |   +--ro link-ref ->
  |   |   |   /nd:networks/network[nd:network-id=current()/../network-
  |   |   |   ref]/lnk:link/link-id

```

```

| | +--ro network-ref?    -> /nd:networks/network/network-id
|--ro path-constraints
|   |--ro path-metric-bound* [metric-type]
|     |   +--ro metric-type      identityref
|     |   +--ro upper-bound?    uint64
|   +--ro topology-id?        te-types:te-topology-id
|   +--ro ignore-overload?    boolean
|   +--ro bandwidth-generic
|     |   +--ro te-bandwidth
|           +--ro (technology)?
|             +---:(psc)
|               |   +--ro psc?          rt-types:bandwidth-ieee-
float32
|               +---:(otn)
|                 |   +--ro otn* [rate-type]
|                   |   +--ro rate-type      identityref
|                   |   +--ro counter?       uint16
|                 +---:(lsc)
|                   |   +--ro wdm* [spectrum slot]
|                     |   +--ro spectrum      identityref
|                     |   +--ro slot         int16
|                     |   +--ro width?       uint16
|                 +---:(generic)
|                   |   +--ro generic?       te-bandwidth
disjointness
|   +--ro disjointness?      te-types:te-path-
|   +--ro setup-priority?    uint8
|   +--ro hold-priority?     uint8
|   +--ro signaling-type?    identityref
|   +--ro path-affinities
|     |   +--ro constraint* [usage]
|     |   |   +--ro usage      identityref
|     |   |   +--ro value?    admin-groups
|   +--ro path-srlgs
|     |   +--ro usage?      identityref
|     |   +--ro values*    srlg
|   +--ro path-id            yang-types:uuid
+--ro pathComputationService
  +--ro _path-ref*          -> /paths/path/path-id

```

```

+--ro _servicePort
|   +--ro source?          inet:ip-address
|   +--ro destination?     inet:ip-address
|   +--ro src-tp-id?       binary
|   +--ro dst-tp-id?       binary
|   +--ro bidirectional
|       +--ro association
|           +--ro id?          uint16
|           +--ro source?      inet:ip-address
|           +--ro global-source? inet:ip-address
|           +--ro type?        identityref
|           +--ro provisioing? identityref
+--ro path-constraints
|   +--ro path-metric-bound* [metric-type]
|       |   +--ro metric-type    identityref
|       |   +--ro upper-bound?   uint64
|   +--ro topology-id?       te-types:te-topology-id
|   +--ro ignore-overload?    boolean
|   +--ro bandwidth-generic
|       |   +--ro te-bandwidth
|       |       +--ro (technology)?
|       |           +--:(psc)
|       |               |   +--ro psc?          rt-types:bandwidth-ieee-
float32 |
|       |   +--:(otn)
|       |       |   +--ro otn* [rate-type]
|       |       |       +--ro rate-type    identityref
|       |       |       +--ro counter?     uint16
|       |   +--:(lsc)
|       |       |   +--ro wdm* [spectrum slot]
|       |       |       +--ro spectrum    identityref
|       |       |       +--ro slot        int16
|       |       |       +--ro width?      uint16
|       |   +--:(generic)
|       |       +--ro generic?    te-bandwidth
+--ro disjointness?          te-types:te-path-disjointness
+--ro setup-priority?        uint8
+--ro hold-priority?         uint8
+--ro signaling-type?        identityref

```

```

|   +--ro path-affinities
|   |   +--ro constraint* [usage]
|   |   |   +--ro usage      identityref
|   |   |   +--ro value?    admin-groups
|   +--ro path-srlgs
|   |   +--ro usage?      identityref
|   |   +--ro values*    srlg
+--ro optimizations
|   +--ro (algorithm)?
|   |   +--:(metric) {path-optimization-metric}?
|   |   |   +--ro optimization-metric* [metric-type]
|   |   |   |   +--ro metric-type      identityref
|   |   |   |   +--ro weight?          uint8
|   |   |   +--ro tiebreakers
|   |   |   |   +--ro tiebreaker* [tiebreaker-type]
|   |   |   |   +--ro tiebreaker-type identityref
|   |   +--:(objective-function) {path-optimization-objective-
function}?
|   |   |   +--ro objective-function
|   |   |   |   +--ro objective-function-type? identityref
augment /te:tunnels-rpc/te:input/te:tunnel-info:
+---- request-list* [request-id-number]
|   +---- request-id-number      uint32
|   +---- servicePort*
|   |   +---- source?            inet:ip-address
|   |   +---- destination?       inet:ip-address
|   |   +---- src-tp-id?         binary
|   |   +---- dst-tp-id?         binary
|   |   +---- bidirectional
|   |   |   +---- association
|   |   |   |   +---- id?          uint16
|   |   |   |   +---- source?      inet:ip-address
|   |   |   |   +---- global-source? inet:ip-address
|   |   |   |   +---- type?        identityref
|   |   |   |   +---- provisioing? identityref
|   +---- path-constraints
|   |   +---- path-metric-bound* [metric-type]
|   |   |   +---- metric-type      identityref
|   |   |   +---- upper-bound?    uint64

```



```

| | +---- topology-id?          te-types:te-topology-id
| | +---- ignore-overload?      boolean
| | +---- bandwidth-generic
| | | +---- te-bandwidth
| | | | +---- (technology)?
| | | | | +---:(psc)
| | | | | | +---- psc?          rt-types:bandwidth-ieee-
float32
| | | | | +---:(otn)
| | | | | | +---- otn* [rate-type]
| | | | | | | +---- rate-type    identityref
| | | | | | | +---- counter?    uint16
| | | | | +---:(lsc)
| | | | | | +---- wdm* [spectrum slot]
| | | | | | | +---- spectrum    identityref
| | | | | | | +---- slot        int16
| | | | | | | +---- width?      uint16
| | | | | +---:(generic)
| | | | | | +---- generic?      te-bandwidth
| | +---- disjointness?        te-types:te-path-disjointness
| | +---- setup-priority?      uint8
| | +---- hold-priority?       uint8
| | +---- signaling-type?      identityref
| | +---- path-affinities
| | | +---- constraint* [usage]
| | | | +---- usage            identityref
| | | | +---- value?          admin-groups
| | +---- path-srlgs
| | | +---- usage?            identityref
| | | +---- values*          srlg
+---- optimizations
| +---- (algorithm)?
| | +---:(metric) {path-optimization-metric}?
| | | +---- optimization-metric* [metric-type]
| | | | +---- metric-type      identityref
| | | | +---- weight?          uint8
| | +---- tiebreakers
| | | +---- tiebreaker* [tiebreaker-type]
| | | | +---- tiebreaker-type  identityref

```

```

|          +---:(objective-function) {path-optimization-objective-
function}?
|          +----- objective-function
|          |          +----- objective-function-type?  identityref
+----- synchronization* [synchronization-index]
|          +----- synchronization-index      uint32
+----- svec
|          +----- relaxable?                  boolean
|          +----- link-diverse?              boolean
|          +----- node-diverse?              boolean
|          +----- srlg-diverse?              boolean
|          +----- request-id-number*         uint32
+----- path-constraints
|          +----- path-metric-bound* [metric-type]
|          |          +----- metric-type      identityref
|          |          +----- upper-bound?    uint64
+----- topology-id?      te-types:te-topology-id
+----- ignore-overload?  boolean
+----- bandwidth-generic
|          +----- te-bandwidth
|          |          +----- (technology)?
|          |          |          +---:(psc)
|          |          |          |          +----- psc?      rt-types:bandwidth-ieee-
float32
|          |          |          |          |
|          |          |          |          +---:(otn)
|          |          |          |          |          +----- otn* [rate-type]
|          |          |          |          |          |          +----- rate-type  identityref
|          |          |          |          |          |          +----- counter?    uint16
|          |          |          |          |          +---:(lsc)
|          |          |          |          |          |          +----- wdm* [spectrum slot]
|          |          |          |          |          |          |          +----- spectrum  identityref
|          |          |          |          |          |          |          +----- slot      int16
|          |          |          |          |          |          |          +----- width?    uint16
|          |          |          |          |          +---:(generic)
|          |          |          |          |          |          +----- generic?    te-bandwidth
+----- disjointness?      te-types:te-path-disjointness
+----- setup-priority?    uint8
+----- hold-priority?     uint8
+----- signaling-type?    identityref

```

```

+---- path-affinities
|   +---- constraint* [usage]
|       +---- usage      identityref
|       +---- value?     admin-groups
+---- path-srlgs
|   +---- usage?        identityref
|   +---- values*       srlg
augment /te:tunnels-rpc/te:output/te:result:
+--ro response* [response-index]
+--ro response-index      uint32
+--ro (response-type)?
+--:(no-path-case)
|   +--ro no-path
+--:(path-case)
+--ro pathCompService
+--ro _path-ref*           -> /paths/path/path-id
+--ro _servicePort
|   +--ro source?          inet:ip-address
|   +--ro destination?    inet:ip-address
|   +--ro src-tp-id?       binary
|   +--ro dst-tp-id?       binary
|   +--ro bidirectional
|       +--ro association
|           +--ro id?          uint16
|           +--ro source?      inet:ip-address
|           +--ro global-source? inet:ip-address
|           +--ro type?        identityref
|           +--ro provisioing? identityref
+--ro path-constraints
|   +--ro path-metric-bound* [metric-type]
|       |   +--ro metric-type    identityref
|       |   +--ro upper-bound?   uint64
|       +--ro topology-id?       te-types:te-topology-
id
|   +--ro ignore-overload?    boolean
+--ro bandwidth-generic
|   +--ro te-bandwidth
|       +--ro (technology)?
|       +--:(psc)

```

```

| | | | +--ro psc?          rt-types:bandwidth-
ieee-float32
| | | | +--:(otn)
| | | | | +--ro otn* [rate-type]
| | | | | | +--ro rate-type      identityref
| | | | | | +--ro counter?     uint16
| | | | +--:(lsc)
| | | | | +--ro wdm* [spectrum slot]
| | | | | | +--ro spectrum      identityref
| | | | | | +--ro slot         int16
| | | | | | +--ro width?       uint16
| | | | +--:(generic)
| | | | | +--ro generic?       te-bandwidth
disjointness
| | | | +--ro disjointness?    te-types:te-path-
| | | | +--ro setup-priority?   uint8
| | | | +--ro hold-priority?    uint8
| | | | +--ro signaling-type?   identityref
| | | | +--ro path-affinities
| | | | | +--ro constraint* [usage]
| | | | | | +--ro usage        identityref
| | | | | | +--ro value?      admin-groups
| | | | +--ro path-srlgs
| | | | | +--ro usage?         identityref
| | | | | +--ro values*       srlg
+--ro optimizations
+--ro (algorithm)?
+--:(metric) {path-optimization-metric}?
| | +--ro optimization-metric* [metric-type]
| | | +--ro metric-type      identityref
| | | +--ro weight?         uint8
| | +--ro tiebreakers
| | | +--ro tiebreaker* [tiebreaker-type]
| | | | +--ro tiebreaker-type identityref
+--:(objective-function) {path-optimization-
objective-function}?
+--ro objective-function
+--ro objective-function-type?
identityref
```

Figure 9 - TE path computation tree

6.2.2. YANG Module

```
<CODE BEGINS>file " ietf-te-path-computation.yang "  
module ietf-te-path-computation {  
  yang-version 1.1;  
  namespace "urn:ietf:params:xml:ns:yang:ietf-te-path-computation";  
  // replace with IANA namespace when assigned  
  
  prefix "tepc";  
  
  import ietf-inet-types {  
    prefix "inet";  
  }  
  
  import ietf-yang-types {  
    prefix "yang-types";  
  }  
  
  import ietf-network-topology {  
    prefix "nt";  
  }  
  
  import ietf-te {  
    prefix "te";  
  }  
  
  import ietf-te-types {  
    prefix "te-types";  
  }  
  
  organization  
    "Traffic Engineering Architecture and Signaling (TEAS)  
    Working Group";  
  
  contact  
    "WG Web:    <http://tools.ietf.org/wg/teas/>  
    WG List:    <mailto:teas@ietf.org>
```

```
WG Chair: Lou Berger
          <mailto:lberger@labn.net>

WG Chair: Vishnu Pavan Beeram
          <mailto:vbeeram@juniper.net>

";

description "YANG model for stateless TE path computation";

revision "2016-10-10" {
  description "Initial revision";
  reference "YANG model for stateless TE path computation";
}

/*
 * Features
 */

feature stateless-path-computation {
  description
    "This feature indicates that the system supports
    stateless path computation.";
}

/*
 * Groupings
 */

grouping Path {
  list _telink {
    key 'link-ref';
    config false;
    uses nt:link-ref;
    description "List of telink refs.";
  }
  uses te-types:generic-path-constraints;
```

```
    leaf path-id {
      type yang-types:uuid;
      config false;
      description "path-id ref.";
    }
    description "Path is described by an ordered list of TE Links.";
  }

  grouping PathCompServicePort {
    leaf source {
      type inet:ip-address;
      description "TE tunnel source address.";
    }
    leaf destination {
      type inet:ip-address;
      description "P2P tunnel destination address";
    }
    leaf src-tp-id {
      type binary;
      description "TE tunnel source termination point identifier.";
    }
    leaf dst-tp-id {
      type binary;
      description "TE tunnel destination termination point
identifier.";
    }
    uses te:bidir-assoc-properties;
    description "Path Computation Service Port grouping.";
  }

  grouping PathComputationService {
    leaf-list _path-ref {
      type leafref {
        path '/paths/path/path-id';
      }
      config false;
      description "List of previously computed path references.";
    }
  }
```

```
    container _servicePort {
      uses PathCompServicePort;
      description "Path Computation Service Port.";
    }
    uses te-types:generic-path-constraints;
    uses te-types:generic-path-optimization;

    description "Path computation service.";
  }

  grouping synchronization-info {
    description "Information for sync";
    list synchronization {
      key "synchronization-index";
      description "sync list";
      leaf synchronization-index {
        type uint32;
        description "index";
      }
      container svec {
        description
          "Synchronization VECtor";
        leaf relaxable {
          type boolean;
          default true;
          description
            "If this leaf is true, path computation process is free
to ignore svec content.
            otherwise it must take into account this svec.";
        }
        leaf link-diverse {
          type boolean;
          default false;
          description "link-diverse";
        }
        leaf node-diverse {
```



```
        type boolean;
        default false;
        description "node-diverse";
    }
    leaf srlg-diverse {
        type boolean;
        default false;
        description "srlg-diverse";
    }
    leaf-list request-id-number {
        type uint32;
        description
            "This list reports the set of M path computation requests
that must be synchronized.";
    }
    }
    uses te-types:generic-path-constraints;
}

grouping no-path-info {
    description "no-path-info";
    container no-path {
        description "no-path container";
    }
}

/*
 * Root container
 */
container paths {
    list path {
        key "path-id";
        config false;
        uses Path;

        description "List of previous computed paths.";
    }
    description "Root container for path-computation";
}
```

```
}

container pathComputationService {
  config false;
  uses PathComputationService;
  description "Service for computing paths.";
}

/**
 * AUGMENTS TO TE RPC
 */

augment "/te:tunnels-rpc/te:input/te:tunnel-info" {
  description "statelessComputeP2PPath input";
  list request-list {
    key "request-id-number";
    description "request-list";
    leaf request-id-number {
      type uint32;
      mandatory true;
      description "Each path computation request is uniquely
identified by the request-id-number.
      It must be present also in rpcs.";
    }
    list servicePort {
      min-elements 1;
      uses PathCompServicePort;
      description "List of service ports.";
    }
    uses te-types:generic-path-constraints;
    uses te-types:generic-path-optimization;
  }
  uses synchronization-info;
}

augment "/te:tunnels-rpc/te:output/te:result" {
```

```
description "statelessComputeP2PPath output";
list response {
    key response-index;
    config false;
    description "response";
    leaf response-index {
        type uint32;
        description
            "The list key that has to reuse request-id-number.";
    }
    choice response-type {
        config false;
        description "response-type";
        case no-path-case {
            uses no-path-info;
        }
        case path-case {
            container pathCompService {
                uses PathComputationService;
                description "Path computation service.";
            }
        }
    }
}
}
}
}
<CODE ENDS>
```

Figure 10 - TE path computation YANG module

7. Security Considerations

This document describes use cases of requesting Path Computation using YANG models, which could be used at the ABNO Control Interface [RFC7491] and/or between controllers in ACTN [ACTN-frame]. As such, it does not introduce any new security considerations compared to the ones related to YANG specification, ABNO specification and ACTN Framework defined in [RFC6020], [RFC7950], [RFC7491] and [ACTN-frame].

This document also defines common data types using the YANG data modeling language. The definitions themselves have no security impact on the Internet, but the usage of these definitions in concrete YANG modules might have. The security considerations spelled out in the YANG specification [RFC6020] apply for this document as well.

8. IANA Considerations

This section is for further study: to be completed when the YANG model is more stable.

9. References

9.1. Normative References

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- [RFC7139] Zhang, F. et al., "GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks", RFC 7139, March 2014.
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[ITU-T G.709-2016] ITU-T Recommendation G.709 (06/16), "Interface for the optical transport network", June 2016

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[RFC5541] Le Roux, JL. et al., " Encoding of Objective Functions in the Path Computation Element Communication Protocol (PCEP)", RFC 5541, June 2009.

[RFC7446] Lee, Y. et al., "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

[OTN-TOPO] Zheng, H. et al., "A YANG Data Model for Optical Transport Network Topology", draft-ietf-ccamp-otn-topo-yang, work in progress.

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BGP community based PCE in native IP network
draft-huang-teas-bgp-community-pce-00

Abstract

This document describes a BGP community based method to steer traffic under the PCE architecture in the native IP network.

Status of This Memo

This Internet-Draft is submitted to IETF in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

In the draft [I-D.wang-teas-pce-native-ip], the scenario for TE in native IP network is described and a dual/multi-BGP sessions solution is proposed to meet the TE requirements. This document is for the same scenario and requirements as [I-D.wang-teas-pce-native-ip], however, a BGP community based method is used for steering traffic instead of dual/multi-BGP sessions.

2. Terminology and Abbreviations

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

3. Machanism

To differentiate traffics with various priority, BGP community is used to classify route prefixes. Assign a specific next-hop address for a specific BGP community which could be done by BGP route policy. Then through controlling the path for a specific next-hop address we can steer the related traffic.

The following is an example with a simple topology:

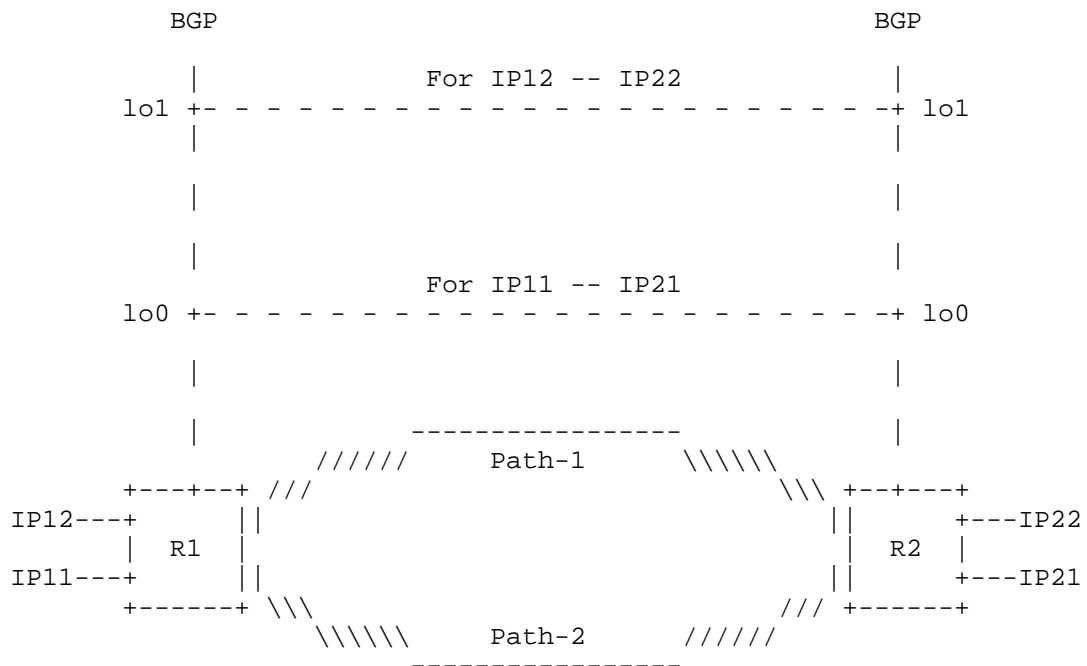


Figure 1: A simple topology as an example

In this topology, assume traffic between IP11 and IP21 is normal traffic, traffic between IP12 and IP22 is high priority. The following procedures can fulfill the differentiated traffic steering:

- (1) On R1, assign BGP community 100:100 for IP11 and 100:200 for IP12. On R2, assign BGP community 100:100 for IP21 and 100:200 for IP22.
- (2) On R1, use BGP route policy to set the next-hop as lo0 for prefixes with community 100:100 and lo1 for prefixes with community 100:200. Make the same configuration on R2.
- (3) On R1, set an explicit route to R2's lo0 through path-1 and another explicit route to R2's lo1 through path-2. On R2, set an explicit route to R1's lo0 through path-1 and another explicit route to R1's lo1 through path-2.

Through the above procedures traffic with different priority can be steered to appointed path as needed. More BGP communities and loopback interfaces/addresses can be created for more traffic classes in a more complex environment.

In a PCE enabled network, the above procedures can be fulfilled in a automated way. PCE can set the binding of BGP community and route prefixes, BGP community and next-hops/loopback addresses. PCE can change the BGP community for specific prefixes to steer the related traffic to a different priority/path. PCE also can set explicit route hop by hop for a specific next-hop/loopback address to steer the related traffic as needed. In addition, PCEP need to be extended to transfer the necessary parameters, such as BGP communities, next-hop/loopback addresses, related route prefixes and explicit route for a specific next-hop. How to extend PCEP is out of this document's scope.

4. Security Considerations
5. IANA Considerations
6. Normative References

[I-D.wang-teas-pce-native-ip]

Wang, A., Zhao, Q., Khasanov, B., Mi, K., Mallya, R., and S. Peng, "PCE in Native IP Network", draft-wang-teas-pce-native-ip-03 (work in progress), March 2017.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.

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A YANG Data Model for Optical Transport Network Topology
draft-ietf-ccamp-otn-topo-yang-14

Abstract

This document describes a YANG data model to describe the topologies of an Optical Transport Network (OTN). It is independent of control plane protocols and captures topological and resource related information pertaining to OTN. This model enables clients, which interact with a transport domain controller, for OTN topology related operations such as obtaining the relevant topology resource information.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

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1. Introduction

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed of equipments utilizing any of a number of different transport technologies such as the Optical Transport Networks (OTN) or packet transport such as provided by the MPLS-Transport Profile (MPLS-TP).

This document defines a data model of an OTN network topology, using YANG [RFC7950]. The model can be used by an application exposing to a transport controller. Furthermore, it can be used by an application for the following purposes (but not limited to):

- * To obtain a whole view of the network topology information of its interest;
- * To receive notifications with regard to the information change of the OTN topology;
- * To enforce the establishment and update of a network topology with the characteristic specified in the data model;

The YANG model defined in this document is independent of control plane protocols and captures topology related information pertaining to an Optical Transport Networks (OTN) electrical layer, as the scope specified by [RFC7062]. Furthermore, it is not a stand-alone model, but augmenting from the TE topology YANG model defined in [RFC8795], and importing from the generic Layer 1 types defined in [I-D.ietf-ccamp-layer1-types]. Following TE topology YANG model, the YANG model defined in this document is interface independent. The model is included in [I-D.ietf-teas-actn-yang], which indicates the typical usage of IETF YANG models in ACTN architecture specified by [RFC8453]. More specifically, the usage of this model between controllers is described in [I-D.ietf-ccamp-transport-nbi-app-statement].

2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this document is defined in [RFC8340]. They are provided below for reference.

- * Brackets "[" and "]" enclose list keys.
- * Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- * Symbols after data node names: "?" means an optional node, "!" means a presence container, and "*" denotes a list and leaf-list.
- * Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- * Ellipsis ("...") stands for contents of subtrees that are not shown.

- * Some of the key terms used in this document are listed as follow.
- * TS: Tributary Slot.
- * TSG: Tributary Slot Granularity.
- * TPN: Tributary Port Number.

3. YANG Data Model for OTN Topology

3.1. OTN Topology Data Model Overview

This document aims to describe the data model for OTN topology. As a classic Traffic-engineering (TE) technology, OTN provide TDM switching in transport network [ITU-Tg709]. Therefore the YANG module presented in this document augments from a more generic Traffic Engineered (TE) network topology data model, i.e., the ietf-te-topology, as specified in [RFC8795]. In section 6 of [RFC8795], the guideline for augmenting TE topology model was provided, and in this draft we augment the TE topology model to describe the topology in OTN network. Common types, identities and groupings defined in [I-D.ietf-ccamp-layer1-types] are reused in this document. [RFC8345] describes a network topology model and provide the fundamental model for [RFC8795]. However, this work is not directly augmenting [RFC8345]. Figure 1 shows the augmentation relationship.

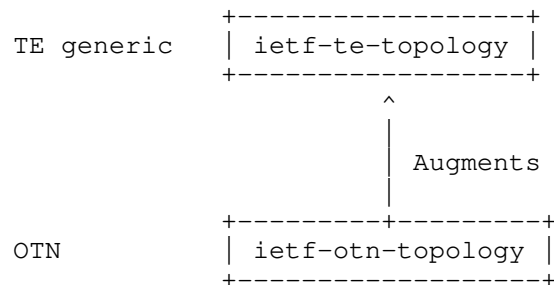


Figure 1 - Relationship between OTN and TE topology models

The entities and TE attributes, such as node, termination points and links, are still applicable for describing an OTN topology and the model presented in this document only specifies with technology-specific attributes/information. The OTN-specific attributes in [RFC7139], including the TPN, TS and TSG, can be used to represent the bandwidth and label information. These attributes have been specified in [I-D.ietf-ccamp-layer1-types], and used in this document for augmentation of the generic TE topology model.

The YANG module `ietf-otn-topology` defined in this document conforms to the Network Management Datastore Architecture (NMDA) defined in [RFC8342].

3.2. Attributes Augmentation

There are a few characteristics augmenting to the generic TE topology.

Following the guidelines in [RFC8795], a `otn-topology network-type` is specified as the indicator of OTN in the topology as follow.

```
augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
  +---rw otn-topology!
```

Two OTN technology-specific parameters are specified to augment the generic TE link attributes.

```
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes:
    +---rw tsg?          identityref
    +---rw distance?     uint32
```

In OTN the resources is measured by the tributary slots (TS), as specified in [RFC7139]. The tributary slot granularity (TSG) attribute defines the granularity, such as 1.25G, 2.5G and 5G, used by the TSs of a given OTN link. The distance attribute describes the geographical distance between a pair of OTN link termination points. This is usually measured by the length of the fibre.

The OTN topology model allows reporting also the access links which are capable of supporting the transparent client signals, defined in [I-D.ietf-ccamp-layer1-types]. These links can also be multi-function access links that can support one or more transparent client signals as well as OTN.

A `client-svc` container is specified to augment the generic TE link termination point to describe if the point is capable of carrying client signal and what kind of signal can be carried as follow.

```

augment /nw:networks/nw:network/nw:node/nt:termination-point
  /tet:te:
    +--rw client-svc!
      +--rw client-facing?          boolean
      +--rw supported-client-signal* identityref

```

The client-facing is an indicator on whether the point is needed to carry client signal. A list of support-client-signal is used to provide the capabilities of client signal specified in [I-D.ietf-ccamp-layer1-types].

3.3. Bandwidth Augmentation

Following the guidelines in [RFC8795], the model augments all the occurrences of the te-bandwidth container with the OTN technology specific attributes using the otn-link-bandwidth and otn-path-bandwidth groupings defined in [I-D.ietf-ccamp-layer1-types].

3.4. Label Augmentation

The model augments all the occurrences of the label-restriction list with OTN technology specific attributes using the otn-label-range-info grouping defined in [I-D.ietf-ccamp-layer1-types].

Moreover, following the guidelines in [RFC8795], the model augments all the occurrences of the te-label container with the OTN technology specific attributes using the otn-label-start-end, otn-label-hop and otn-label-step groupings defined in [I-D.ietf-ccamp-layer1-types].

3.5. YANG Tree for OTN topology

```

module: ietf-otn-topology

augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
  +--rw otn-topology!
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes:
    +--rw tsg?          identityref
    +--rw distance?    uint32
augment /nw:networks/nw:network/nw:node/nt:termination-point
  /tet:te:
    +--rw client-svc!
      +--rw client-facing?          boolean
      +--rw supported-client-signal* identityref
augment /nw:networks/nw:network/nw:node/nt:termination-point/tet:te
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:

```

```

+---:(otn)
  +---rw otn
    +---rw odu-type?                               identityref
    +---rw (oduflex-type)?
      +---:(generic)
        | +---rw nominal-bit-rate                 uint64
      +---:(cbr)
        | +---rw client-type                       identityref
      +---:(gfp-n-k)
        | +---rw gfp-n                             uint8
        | +---rw gfp-k?                           gfp-k
      +---:(flexe-client)
        | +---rw flexe-client                       flexe-client-rate
      +---:(flexe-aware)
        | +---rw flexe-aware-n                     uint16
      +---:(packet)
        +---rw opuflex-payload-rate                uint64
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:path-constraints/tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
  +---rw odu-type    identityref
  +---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
  +---rw odu-type    identityref
  +---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:path-constraints/tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
  +---ro odu-type    identityref
  +---ro number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
  +---ro odu-type    identityref
  +---ro number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te

```

```

        /tet:tunnel-termination-point/tet:client-layer-adaptation
        /tet:switching-capability/tet:te-bandwidth
        /tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw otn
    +---rw odu-type?      identityref
    +---rw (oduflex-type)?
      +---:(generic)
        | +---rw nominal-bit-rate      uint64
      +---:(cbr)
        | +---rw client-type            identityref
      +---:(gfp-n-k)
        | +---rw gfp-n                  uint8
        | +---rw gfp-k?                 gfp-k
      +---:(flexe-client)
        | +---rw flexe-client            flexe-client-rate
      +---:(flexe-aware)
        | +---rw flexe-aware-n          uint16
      +---:(packet)
        +---rw opuflex-payload-rate    uint64
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:max-link-bandwidth
  /tet:te-bandwidth/tet:technology:

```

```

+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:max-resv-link-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:unreserved-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro otn
    +---ro odu-type?      identityref
    +---ro (oduflex-type)?
      +---:(generic)
        | +---ro nominal-bit-rate      uint64
      +---:(cbr)
        | +---ro client-type            identityref
      +---:(gfp-n-k)
        | +---ro gfp-n                  uint8
        | +---ro gfp-k?                 gfp-k
      +---:(flexe-client)
        | +---ro flexe-client            flexe-client-rate
      +---:(flexe-aware)
        | +---ro flexe-aware-n           uint16
      +---:(packet)
        +---ro opuflex-payload-rate      uint64
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry/tet:max-link-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
    +---ro odu-type      identityref
    +---ro number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry/tet:max-resv-link-bandwidth

```

```

        /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---ro odulist* [odu-type]
        +---ro odu-type      identityref
        +---ro number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:unreserved-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---ro odulist* [odu-type]
        +---ro odu-type      identityref
        +---ro number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes
    /tet:interface-switching-capability/tet:max-lsp-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw otn
        +---rw odu-type?          identityref
        +---rw (oduflex-type)?
            +---:(generic)
                | +---rw nominal-bit-rate      uint64
            +---:(cbr)
                | +---rw client-type            identityref
            +---:(gfp-n-k)
                | +---rw gfp-n                  uint8
                | +---rw gfp-k?                 gfp-k
            +---:(flexe-client)
                | +---rw flexe-client            flexe-client-rate
            +---:(flexe-aware)
                | +---rw flexe-aware-n          uint16
            +---:(packet)
                +---rw opuflex-payload-rate    uint64
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:max-link-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw odulist* [odu-type]
        +---rw odu-type      identityref
        +---rw number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:max-resv-link-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw odulist* [odu-type]
        +---rw odu-type      identityref
        +---rw number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template

```

```

        /tet:te-link-attributes/tet:unreserved-bandwidth
        /tet:te-bandwidth/tet:technology:
+---:(otn)
+---rw odulist* [odu-type]
+---rw odu-type    identityref
+---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:from/tet:label-restrictions
        /tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction:
+---ro range-type?    otn-label-range-type
+---ro tsg?           identityref
+---ro odu-type-list* identityref
+---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:from/tet:label-restrictions
        /tet:label-restriction:
+---ro range-type?    otn-label-range-type
+---ro tsg?           identityref
+---ro odu-type-list* identityref
+---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction:

```

```

    +---ro range-type?      otn-label-range-type
    +---ro tsg?             identityref
    +---ro odu-type-list*   identityref
    +---ro priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction:
    +---ro range-type?      otn-label-range-type
    +---ro tsg?             identityref
    +---ro odu-type-list*   identityref
    +---ro priority?        uint8
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-start/tet:te-label/tet:technology:
    +---:(otn)
        +---rw (range-type)?

```



```

      +---:(trib-port)
      |   +---rw otn-tpn?    otn-tpn
      +---:(trib-slot)
          +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-end/tet:te-label/tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-step/tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:primary-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:backup-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)

```

```

    +--rw otn-tpn?    otn-tpn
    +--rw tsg?        identityref
    +--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
    +--rw otn-tpn?    otn-tpn
    +--rw tsg?        identityref
    +--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+--:(otn)
    +--ro otn-tpn?    otn-tpn
    +--ro tsg?        identityref
    +--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    |   +--:(trib-port)
    |   |   +--rw otn-tpn?    otn-tpn
    |   +--:(trib-slot)
    |   |   +--rw otn-ts?     otn-ts
    |   +--rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    |   +--:(trib-port)
    |   |   +--rw otn-tpn?    otn-tpn
    |   +--:(trib-slot)
    |   |   +--rw otn-ts?     otn-ts
    |   +--rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions

```

```

        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
    +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
    +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
    +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
    +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:underlay/tet:primary-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string

```

```

augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-properties
  /tet:path-route-objects/tet:path-route-object/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--ro otn-tpn?    otn-tpn
+--ro tsg?        identityref
+--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-start/tet:te-label/tet:technology:
+--:(otn)
+--ro (range-type)?
+--:(trib-port)
|   +--ro otn-tpn?    otn-tpn

```

```

      +---:(trib-slot)
        +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-end/tet:te-label/tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?      otn-tpn
  +---:(trib-slot)
    +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-step/tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?      otn-tpn
  +---:(trib-slot)
    +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:underlay/tet:primary-path/tet:path-element/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref
  +---ro ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:underlay/tet:backup-path/tet:path-element/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref
  +---ro ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:optimizations/tet:algorithm/tet:metric
  /tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref

```

```

    +--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
    +--ro otn-tpn?    otn-tpn
    +--ro ts-g?       identityref
    +--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+--:(otn)
    +--ro otn-tpn?    otn-tpn
    +--ro ts-g?       identityref
    +--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+--:(otn)
    +--ro (range-type)?
    +--:(trib-port)
    |   +--ro otn-tpn?    otn-tpn
    +--:(trib-slot)
    +--ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+--:(otn)
    +--ro (range-type)?
    +--:(trib-port)
    |   +--ro otn-tpn?    otn-tpn
    +--:(trib-slot)
    +--ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+--:(otn)

```

```

    +---ro (range-type)?
      +---:(trib-port)
        | +---ro otn-tpn?    otn-tpn
      +---:(trib-slot)
        +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:primary-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?    otn-tpn
  +---ro ts-g?      identityref
  +---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices

```

```

        /tet:connectivity-matrix/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:optimizations/tet:algorithm
        /tet:metric/tet:optimization-metric
        /tet:explicit-route-exclude-objects
        /tet:route-object-exclude-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:optimizations/tet:algorithm
        /tet:metric/tet:optimization-metric
        /tet:explicit-route-include-objects
        /tet:route-object-include-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:path-properties
        /tet:path-route-objects/tet:path-route-object/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:tunnel-termination-point
        /tet:local-link-connectivities/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)

```



```

      +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+---:(otn)
  +---rw (range-type)?
  +---:(trib-port)
  |   +---rw otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---rw (range-type)?
  +---:(trib-port)
  |   +---rw otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?      otn-tpn
  +---rw tsg?          identityref
  +---rw ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:backup-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?      otn-tpn
  +---rw tsg?          identityref
  +---rw ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)

```

```

    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---ro otn-tpn?    otn-tpn
    +---ro tsg?        identityref
    +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te

```

```

        /tet:tunnel-termination-point
        /tet:local-link-connectivities
        /tet:local-link-connectivity/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---rw (range-type)?
    +---:(trib-port)
      | +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects

```

```

        /tet:route-object-include-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:tunnel-termination-point
        /tet:local-link-connectivities
        /tet:local-link-connectivity/tet:path-properties
        /tet:path-route-objects/tet:path-route-object/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro tsg?        identityref
+---ro ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:underlay/tet:primary-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
|   +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?

```

```

    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(otn)
    +---ro (range-type)?
    +---:(trib-port)
    |   +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(otn)
    +---ro (range-type)?
    +---:(trib-port)
    |   +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
    +---ro (range-type)?
    +---:(trib-port)
    |   +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---ro otn-ts?    otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:underlay/tet:primary-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn

```

```

    +--rw tsg?          identityref
    +--rw ts-list?      string
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:underlay/tet:backup-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+--:(otn)
    +--rw otn-tpn?      otn-tpn
    +--rw tsg?          identityref
    +--rw ts-list?      string
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?      otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?       otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?      otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?       otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?      otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?       otn-ts

```

4. The YANG Code

```
<CODE BEGINS> file "ietf-otn-topology@2021-07-08.yang"
module ietf-otn-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-otn-topology";
  prefix "otnt";

  import ietf-network {
    prefix "nw";
    reference "RFC 8345: A YANG Data Model for Network Topologies";
  }

  import ietf-network-topology {
    prefix "nt";
    reference "RFC 8345: A YANG Data Model for Network Topologies";
  }

  import ietf-te-topology {
    prefix "tet";
    reference
      "RFC 8795: YANG Data Model for Traffic Engineering
      (TE) Topologies";
  }

  import ietf-layer1-types {
    prefix "l1-types";
    reference
      "I-D.ietf-ccamp-layer1-types: A YANG Data Model
      for Layer 1 Types";
  }

  organization
    "IETF CCAMP Working Group";
  contact
    "WG Web: <http://tools.ietf.org/wg/ccamp/>
    WG List: <mailto:ccamp@ietf.org>

    Editor: Haomian Zheng
           <mailto:zhenghaomian@huawei.com>

    Editor: Italo Busi
           <mailto:italo.busi@huawei.com>

    Editor: Xufeng Liu
           <mailto:xufeng.liu.ietf@gmail.com>

    Editor: Sergio Belotti
           <mailto:sergio.belotti@nokia.com>
```

Editor: Oscar Gonzalez de Dios
<mailto:oscar.gonzalezdedios@telefonica.com>;

description

"This module defines a protocol independent Layer 1/ODU topology data model. The model fully conforms to the Network Management Datastore Architecture (NMDA).

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Redistribution and use in source and binary forms, with or without modification, is permitted pursuant to, and subject to the license terms contained in, the Simplified BSD License set forth in Section 4.c of the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>). This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.";

revision 2021-07-08 {

description

"Initial Revision";

reference

"RFC XXXX: A YANG Data Model for Optical Transport Network Topology";

// RFC Ed.: replace XXXX with actual RFC number, update date
// information and remove this note

}

/*

* Data nodes

*/

augment "/nw:networks/nw:network/nw:network-types/"

+ "tet:te-topology" {

container otn-topology {

presence "indicates a topology type of Optical Transport Network (OTN)-electrical layer.";

description "otn topology type";

}

description "augment network types to include otn network";

}

augment "/nw:networks/nw:network/nt:link/tet:te/"

+ "tet:te-link-attributes" {

when "../..../nw:network-types/tet:te-topology/"

+ "otnt:otn-topology" {


```
    description "Augment only for otn network.";
  }
  description "Augment link configuration";

  leaf tsg {
    type identityref {
      base ll-types:tributary-slot-granularity;
    }
    description "Tributary slot granularity.";
    reference
      "G.709/Y.1331, February 2016: Interfaces for the
      Optical Transport Network (OTN)";
  }
  leaf distance {
    type uint32;
    description "distance in the unit of kilometers";
  }
}

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
  + "tet:te" {
  when "../..../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description "Augment only for otn network";
  }
  description "OTN TP attributes config in ODU topology.";

  container client-svc {
    presence "client-facing LTP.";
    description
      "OTN LTP Service attributes.";

    leaf client-facing {
      type boolean;
      default 'false';
      description
        "Indicates whether this LTP is a client-facing LTP.";
    }
    leaf-list supported-client-signal {
      type identityref {
        base ll-types:client-signal;
      }
      description
        "List of client signal types supported by the LTP.";
    }
  }
}
```

```

/*
 * Augment TE bandwidth
 */

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
    + "tet:te/"
    + "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
when "../.../../.../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment maximum LSP TE bandwidth for the link termination
    point (LTP).";
case otn {
uses ll-types:otn-path-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../.../../.../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE bandwidth path constraints of the TE node
    connectivity matrices.";
case otn {
uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../.../../.../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
}
```

```

    }
    description
      "Augment TE bandwidth path constraints of the
       connectivity matrix entry.";
    case otn {
      uses ll-types:otn-link-bandwidth;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE bandwidth path constraints of the TE node
     connectivity matrices information source.";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE bandwidth path constraints of the
     connectivity matrix entry information source";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:client-layer-adaptation/tet:switching-capability/"
  + "tet:te-bandwidth/tet:technology" {

```

```

when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment client TE bandwidth of the tunnel termination point
  (TTP)";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/tet:path-constraints/"
+ "tet:te-bandwidth/tet:technology" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE bandwidth path constraints for the TTP
  Local Link Connectivities.";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/tet:path-constraints/"
+ "tet:te-bandwidth/tet:technology" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE bandwidth path constraints for the TTP
  Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

```

```

    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment maximum LSP TE bandwidth for the TE link.";
    case otn {
      uses ll-types:otn-path-bandwidth;
    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:max-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment maximum TE bandwidth for the TE link";
    case otn {
      uses ll-types:otn-link-bandwidth;
    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:max-resv-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description

```

```
    "Augment maximum reservable TE bandwidth for the TE link";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:unreserved-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment unreserved TE bandwidth for the TE Link";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:interface-switching-capability/"
  + "tet:max-lsp-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment maximum LSP TE bandwidth for the TE link
    information source";
  case otn {
    uses ll-types:otn-path-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:max-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
```

```
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment maximum TE bandwidth for the TE link
        information source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:max-resv-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../.../.../nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment maximum reservable TE bandwidth for the TE link
        information-source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:unreserved-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../.../.../nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment unreserved TE bandwidth of the TE link
        information source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}
```

```
augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:interface-switching-capability/"
  + "tet:max-lsp-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum LSP TE bandwidth of the TE link
    template";
  case otn {
    uses ll-types:otn-path-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:max-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum TE bandwidth the TE link template";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:max-resv-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum reservable TE bandwidth for the TE link
    template.";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:unreserved-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment unreserved TE bandwidth the TE link template";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

/*
```



```
* Augment TE label range information
*/

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the TE node
    connectivity matrices.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the source LTP
    of the connectivity matrix entry.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the destination LTP
    of the connectivity matrix entry.";
uses ll-types:otn-label-range-info;
```

```

}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/"
+ "tet:connectivity-matrices/tet:label-restrictions/"
+ "tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range information for the TE node
      connectivity matrices information source.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:from/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range information for the source LTP
      of the connectivity matrix entry information source.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:to/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range information for the destination LTP
      of the connectivity matrix entry information source.";
uses ll-types:otn-label-range-info;

```

```

}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TTP
Local Link Connectivities.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TTP
Local Link Connectivity entry.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TE link.";
uses ll-types:otn-label-range-info;
}

```

```
augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:label-restrictions/tet:label-restriction" {
when "../.../.../.../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range information for the TE link
  information source.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction" {
  description
    "Augment TE label range information for the TE link template.";
uses ll-types:otn-label-range-info;
}

/*
 * Augment TE label
 */

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the TE node
  connectivity matrices";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
```

```
+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when ".../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../..."nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range end for the TE node
      connectivity matrices";
case otn {
    uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-step/"
+ "tet:technology" {
when ".../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../..."nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range step for the TE node
      connectivity matrices";
case otn {
    uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when ".../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../.../..."nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
```

```

    description
      "Augment TE label hop for the underlay primary path of the
       TE node connectivity matrices";
    case otn {
      uses ll-types:otn-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:underlay/tet:backup-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path of the
     TE node connectivity matrices";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
     by the path computation of the TE node connectivity
     matrices";
  case otn {

```

```

    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the TE node connectivity
  matrices";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the TE node connectivity matrices";
case otn {
  uses ll-types:otn-label-hop;
}
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the source LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range end for the source LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {

```



```

when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
  }
  description
    "Augment TE label range step for the source LTP
    of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-step;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
  }
  description
    "Augment TE label range start for the destination LTP
    of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";

```

```

    }
    description
      "Augment TE label range end for the destination LTP
      of the connectivity matrix entry.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

```

```

    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/"
    + "tet:type/tet:label/tet:label-hop/"
    + "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path
    of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"
  + "tet:algorithm/tet:metric/tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"

```

```

    + "tet:connectivity-matrix/tet:optimizations/"
    + "tet:algorithm/tet:metric/tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the connectivity matrix entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the connectivity matrix entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"

```

```

    + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
         OTN topology type.";
    }
  description
    "Augment TE label range start for the TE node connectivity
     matrices information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label range end for the TE node connectivity
     matrices information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-step/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label range step for the TE node connectivity
     matrices information source.";

```

```

    case otn {
      uses ll-types:otn-label-step;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay primary path
    of the TE node connectivity matrices of the information
    source entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path
    of the TE node connectivity matrices of the information
    source entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:optimizations/tet:algorithm/tet:metric/"

```

```

    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TE node connectivity matrices
    information source.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TE node connectivity matrices
    information source.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {

```

```

when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the TE node connectivity matrices information source.";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the source LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
}

```



```

    description
      "Augment TE label range end for the source LTP
      of the connectivity matrix entry information source.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the source LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range end for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the connectivity matrix entry information source.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the connectivity matrix entry information source.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description

```

```

    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the connectivity matrix entry
    information source.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the connectivity matrix entry
  information source.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the connectivity matrix entry information source.";

```

```

    case otn {
      uses ll-types:otn-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label range start for the TTP
    Local Link Connectivities.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label range end for the TTP
    Local Link Connectivities.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology"{
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label range step for the TTP
        Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-step;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-exclude-objects/"
+ "tet:route-object-exclude-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivities.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description

```

```

        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects included
        by the path computation of the TTP Local Link
        Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the computed path route objects
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label range start for the TTP

```



```

        Local Link Connectivity entry.";
    case otn {
        uses ll-types:otn-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE label range end for the TTP
    Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE label range step for the TTP
    Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-step;
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the TTP Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the TTP Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```

```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TTP Local Link
    Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"

```

```

    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the TTP Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}
augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the underlay primary path
    of the TE link.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description

```

```

    "Augment TE label hop for the underlay backup path
      of the TE link.";
  case otn {
    uses l1-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range start for the TE link.";
  case otn {
    uses l1-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range end for the TE link.";
  case otn {
    uses l1-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description

```

```

    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
  "Augment TE label range step for the TE link.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
  "Augment TE label range start for the TE link
    information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
  "Augment TE label range end for the TE link
    information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"

```

```

    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/tet:technology" {
when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label range step for the TE link
        information source.";
    case otn {
        uses ll-types:otn-label-step;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    description
        "Augment TE label hop for the underlay primary path
        of the TE link template.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    description
        "Augment TE label hop for the underlay backup path
        of the TE link template.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    description
        "Augment TE label range start for the TE link template.";
    case otn {
        uses ll-types:otn-label-start-end;
    }
}

```

```

    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    description
      "Augment TE label range end for the TE link template.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/tet:technology" {
    description
      "Augment TE label range step for the TE link template.";
    case otn {
      uses ll-types:otn-label-step;
    }
  }
}
<CODE ENDS>

```

5. IANA Considerations

It is proposed to IANA to assign new URIs from the "IETF XML Registry" [RFC3688] as follows:

```

URI: urn:ietf:params:xml:ns:yang:ietf-otn-topology
Registrant Contact: The IESG
XML: N/A; the requested URI is an XML namespace.

```

This document registers a YANG module in the YANG Module Names registry [RFC7950].

```

name:      ietf-otn-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-otn-topology
prefix:    otnt
reference:  RFC XXXX

```


6. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

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9. References

9.1. Normative References

[I-D.ietf-ccamp-layer1-types]

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A YANG Data Model for WSON (Wavelength Switched Optical Networks)
draft-ietf-ccamp-wson-yang-28

Abstract

This document provides a YANG data model for the routing and wavelength assignment (RWA) TE topology in wavelength switched optical networks (WSONs). The YANG data model defined in this document conforms to the Network Management Datastore Architecture (NMDA).

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1. Introduction

This document provides a YANG data model for the routing and wavelength assignment (RWA) Traffic Engineering (TE) topology in transparent wavelength switched optical networks (WSONs). The YANG model described in this document is a WSON technology-specific YANG model based on the information model developed in [RFC7446] and the two encoding documents [RFC7581] and [RFC7579] that developed protocol independent encodings based on [RFC7446].

[ITU-Tg6982] defines amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces. The YANG data model defined in this document refers to the standard application mode defined in [ITU-Tg6982].

What is not in scope of this document is both impairment-aware optical networks and flexi-grid. Refer to [I-D.ietf-ccamp-optical-impairment-topology-yang] for impairment-aware optical network topology model and [I-D.ietf-ccamp-flexigrid-yang] for flexi-grid optical network topology model.

Additionally, transponders and resource blocks (e.g., 3R Regeneration) models are not in the scope of this document.

This document defines one YANG model: ietf-wson-topology (Section 3). This document augments the generic TE topology draft [RFC8795].

There are multiple applications for the yang data model defined in this document. For example, nodes within the network can use the data model to capture their understanding of the overall WSON topology and expose it to a controller. A controller can further propagate the topology to other controllers. The YANG model is used by NETCONF [RFC6020], [RFC8341] or a RESTCONF [RFC8040] protocol. The YANG data model defined in this document conforms to the Network Management Datastore Architecture [RFC8342].

1.1. Terminology and Notations

Refer to [RFC7446] and [RFC7581] for the key terms used in this document. The following terms are defined in [RFC7950] and are not redefined here:

- o client
- o server
- o augment
- o data model
- o data node

The following terms are defined in [RFC6241] and are not redefined here:

- o configuration data
- o state data

The terminology for describing YANG data models is found in [RFC7950].

1.2. Tree Diagram

A simplified graphical representation of the data model is used in Section 2 of this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

1.3. Prefix in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in the following table.

Prefix	YANG module	Reference
10-types	ietf-layer0-types	[ietf-ccamp-layer0-types]
wson	ietf-wson-topology	[RFCXXXX]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[RFC8795]

Note: The RFC Editor will replace XXXX with the number assigned to the RFC once this draft becomes an RFC.

2. YANG Model (Tree Structure) for WSON topology

```

module: ietf-wson-topology
  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw wson-topology!
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes:
      +--rw wson-node!
      +--rw is-reconfigurable-node?  boolean
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction:
      +--rw grid-type?  identityref
      +--rw priority?   uint8
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction:
      +--rw grid-type?  identityref
      +--rw priority?   uint8
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:to/tet:label-restrictions
    /tet:label-restriction:
      +--rw grid-type?  identityref

```

```

    +---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?     uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?     uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:to/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?     uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?     uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?     uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?     uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?     uint8
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?     uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices

```

```

        /tet:label-restrictions/tet:label-restriction
        /tet:label-start/tet:te-label/tet:technology:
+---: (wson)
+---rw (grid-type)?
+---: (dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---: (cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction
        /tet:label-end/tet:te-label/tet:technology:
+---: (wson)
+---rw (grid-type)?
+---: (dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---: (cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction
        /tet:label-step/tet:technology:
+---: (wson)
+---rw (l0-grid-type)?
+---: (dwdm)
|   +---rw wson-dwdm-channel-spacing?    identityref
+---: (cwdm)
+---rw wson-cwdm-channel-spacing?    identityref
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:underlay/tet:primary-path/tet:path-element/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---: (wson)
+---rw (grid-type)?
+---: (dwdm)
|   +---rw (single-or-super-channel)?
|       +---: (single)
|       |   +---rw dwdm-n?                    10-types:dwdm-n
|       +---: (super)
|       +---rw subcarrier-dwdm-n*    10-types:dwdm-n
+---: (cwdm)
+---rw cwdm-n?                    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:underlay/tet:backup-path/tet:path-element/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---: (wson)
+---rw (grid-type)?

```

```

    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|       +---:(single)
|           |   +---rw dwdm-n?           10-types:dwdm-n
|       +---:(super)
|           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|       +---:(single)
|           |   +---rw dwdm-n?           10-types:dwdm-n
|       +---:(super)
|           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)

```

```

    +--ro (grid-type)?
      +--:(dwdm)
        | +--ro (single-or-super-channel)?
        |   +--:(single)
        |     | +--ro dwdm-n? 10-types:dwdm-n
        |     +--:(super)
        |       +--ro subcarrier-dwdm-n* 10-types:dwdm-n
      +--:(cwdm)
        +--ro cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+--:(wson)
  +--rw (grid-type)?
    +--:(dwdm)
      | +--rw dwdm-n? 10-types:dwdm-n
    +--:(cwdm)
      +--rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+--:(wson)
  +--rw (grid-type)?
    +--:(dwdm)
      | +--rw dwdm-n? 10-types:dwdm-n
    +--:(cwdm)
      +--rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+--:(wson)
  +--rw (l0-grid-type)?
    +--:(dwdm)
      | +--rw wson-dwdm-channel-spacing? identityref
    +--:(cwdm)
      +--rw wson-cwdm-channel-spacing? identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+--:(wson)
  +--rw (grid-type)?

```

```

      +---:(dwdm)
      |   +---rw dwdm-n?   10-types:dwdm-n
      +---:(cwdm)
      |   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:to/tet:label-restrictions
      /tet:label-restriction/tet:label-end/tet:te-label
      /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?   10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:to/tet:label-restrictions
      /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---rw (l0-grid-type)?
+---:(dwdm)
|   +---rw wson-dwdm-channel-spacing?   identityref
+---:(cwdm)
|   +---rw wson-cwdm-channel-spacing?   identityref
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:underlay/tet:primary-path
      /tet:path-element/tet:type/tet:label/tet:label-hop
      /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?   10-types:dwdm-n
|   |   +---:(super)
|   |   |   +---rw subcarrier-dwdm-n*   10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:underlay/tet:backup-path
      /tet:path-element/tet:type/tet:label/tet:label-hop
      /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)

```

```

    +---rw (single-or-super-channel)?
        +---:(single)
            | +---rw dwdm-n?                10-types:dwdm-n
        +---:(super)
            +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
        +---rw cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:optimizations/tet:algorithm
    /tet:metric/tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
        +---:(dwdm)
            | +---rw (single-or-super-channel)?
                +---:(single)
                    | +---rw dwdm-n?                10-types:dwdm-n
                +---:(super)
                    +---rw subcarrier-dwdm-n*    10-types:dwdm-n
            +---:(cwdm)
                +---rw cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:optimizations/tet:algorithm
    /tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
        +---:(dwdm)
            | +---rw (single-or-super-channel)?
                +---:(single)
                    | +---rw dwdm-n?                10-types:dwdm-n
                +---:(super)
                    +---rw subcarrier-dwdm-n*    10-types:dwdm-n
            +---:(cwdm)
                +---rw cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?

```

```

    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           |   +---ro subcarrier-dwdm-n*  10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-start/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro dwdm-n?  10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-end/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro dwdm-n?  10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-step/tet:technology:
+---:(wson)
    +---ro (l0-grid-type)?
    +---:(dwdm)
    |   +---ro wson-dwdm-channel-spacing?  identityref
    +---:(cwdm)
    |   +---ro wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:underlay/tet:primary-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n

```



```

    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:underlay/tet:backup-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n
    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n
    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n

```

```

    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n
    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
    +---ro (l0-grid-type)?
    +---:(dwdm)

```

```

    | +--ro wson-dwdm-channel-spacing?  identityref
    +--:(cwdm)
      +--ro wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro dwdm-n?  10-types:dwdm-n
    +--:(cwdm)
      +--ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro dwdm-n?  10-types:dwdm-n
    +--:(cwdm)
      +--ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+--:(wson)
  +--ro (l0-grid-type)?
  +--:(dwdm)
    | +--ro wson-dwdm-channel-spacing?  identityref
    +--:(cwdm)
      +--ro wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:primary-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro (single-or-super-channel)?
    |   +--:(single)
    |   | +--ro dwdm-n?  10-types:dwdm-n
    |   +--:(super)
    |   | +--ro subcarrier-dwdm-n*  10-types:dwdm-n

```

```

      +---:(cwdm)
        +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)
            +---ro subcarrier-dwdm-n*   10-types:dwdm-n
    +---:(cwdm)
      +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)
            +---ro subcarrier-dwdm-n*   10-types:dwdm-n
    +---:(cwdm)
      +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)

```

```

    |          +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |          +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---ro (grid-type)?
+---:(dwdm)
|   +---ro (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---ro dwdm-n?                10-types:dwdm-n
|   |   +---:(super)
|   |   |   +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
+---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---rw (l0-grid-type)?
+---:(dwdm)
|   +---rw wson-dwdm-channel-spacing?    identityref

```

```

      +---:(cwdm)
        +---rw wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:backup-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)

```

```

      +---rw cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
  +---:(dwdm)
  |   +---rw (single-or-super-channel)?
  |   |   +---:(single)
  |   |   |   +---rw dwdm-n?                        10-types:dwdm-n
  |   |   |   +---:(super)
  |   |   |   +---rw subcarrier-dwdm-n*           10-types:dwdm-n
  |   +---:(cwdm)
  |   +---rw cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:path-properties
  /tet:path-route-objects/tet:path-route-object/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
  +---:(dwdm)
  |   +---ro (single-or-super-channel)?
  |   |   +---:(single)
  |   |   |   +---ro dwdm-n?                        10-types:dwdm-n
  |   |   |   +---:(super)
  |   |   |   +---ro subcarrier-dwdm-n*           10-types:dwdm-n
  |   +---:(cwdm)
  |   +---ro cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(wson)
  +---rw (grid-type)?
  +---:(dwdm)
  |   +---rw dwdm-n?    10-types:dwdm-n
  +---:(cwdm)
  |   +---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities

```

```

        /tet:local-link-connectivity/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw dwdm-n?      10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?      10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
  +---rw (l0-grid-type)?
    +---:(dwdm)
      | +---rw wson-dwdm-channel-spacing?  identityref
    +---:(cwdm)
      +---rw wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw (single-or-super-channel)?
      |   +---:(single)
      |     | +---rw dwdm-n?      10-types:dwdm-n
      |     +---:(super)
      |       +---rw subcarrier-dwdm-n*  10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?      10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw (single-or-super-channel)?
      |   +---:(single)
      |     | +---rw dwdm-n?      10-types:dwdm-n

```



```

    |         +---:(super)
    |         |         +---rw subcarrier-dwdm-n*      10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |         +---rw (single-or-super-channel)?
    |         |         +---:(single)
    |         |         |         +---rw dwdm-n?      10-types:dwdm-n
    |         |         +---:(super)
    |         |         +---rw subcarrier-dwdm-n*      10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |         +---rw (single-or-super-channel)?
    |         |         +---:(single)
    |         |         |         +---rw dwdm-n?      10-types:dwdm-n
    |         |         +---:(super)
    |         |         +---rw subcarrier-dwdm-n*      10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?

```

```

    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:underlay/tet:primary-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:underlay/tet:backup-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw dwdm-n?           10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions

```

```

        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---: (wson)
    +---rw (grid-type)?
        +---: (dwdm)
            | +---rw dwdm-n? 10-types:dwdm-n
        +---: (cwdm)
            +---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---: (wson)
    +---rw (l0-grid-type)?
        +---: (dwdm)
            | +---rw wson-dwdm-channel-spacing? identityref
        +---: (cwdm)
            +---rw wson-cwdm-channel-spacing? identityref
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---: (wson)
    +---ro (grid-type)?
        +---: (dwdm)
            | +---ro dwdm-n? 10-types:dwdm-n
        +---: (cwdm)
            +---ro cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---: (wson)
    +---ro (grid-type)?
        +---: (dwdm)
            | +---ro dwdm-n? 10-types:dwdm-n
        +---: (cwdm)
            +---ro cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---: (wson)
    +---ro (l0-grid-type)?
        +---: (dwdm)
            | +---ro wson-dwdm-channel-spacing? identityref
        +---: (cwdm)
            +---ro wson-cwdm-channel-spacing? identityref
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:underlay/tet:primary-path

```

```

        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?           10-types:dwdm-n
|   |   +---:(super)
|   |       +---rw subcarrier-dwdm-n* 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?           10-types:dwdm-n
|   |   +---:(super)
|   |       +---rw subcarrier-dwdm-n* 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n? 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n? 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions

```

```

        /tet:label-restriction/tet:label-step/tet:technology:
+--:(wson)
  +--rw (l0-grid-type)?
    +--:(dwdm)
    |   +--rw wson-dwdm-channel-spacing?   identityref
    +--:(cwdm)
    |   +--rw wson-cwdm-channel-spacing?   identityref

```

3. The YANG Code for WSON topology

```

<CODE BEGINS> file "ietf-wson-topology@2020-10-16.yang"
module ietf-wson-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-wson-topology";
  prefix "wson";

  import ietf-network {
    prefix "nw";
    reference
      "RFC 8345: A YANG Data Model for Network Topologies";
  }

  import ietf-network-topology {
    prefix "nt";
    reference
      "RFC 8345: A YANG Data Model for Network Topologies";
  }

  import ietf-te-topology {
    prefix "tet";
    reference
      "RFC 8795: YANG Data Model for
      Traffic Engineering (TE) Topologies";
  }

  import ietf-layer0-types {
    prefix "l0-types";
    reference
      "RFC XXXX: A YANG Data Model for Layer 0 Types";
  }

  /* Note: The RFC Editor will replace XXXX with the number assigned
     to the RFC once draft-ietf-ccamp-layer0-types becomes an RFC.*/

  organization

```

```
"IETF CCAMP Working Group";

contact
  "WG Web: <http://tools.ietf.org/wg/ccamp/>
  WG List: <mailto:ccamp@ietf.org>

  Editor: Haomian Zheng
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          <aihuaguo.ietf@gmail.com>
  Editor: Victor Lopez
          <victor.lopezalvarez@telefonica.com>

  Editor: Daniel King
          <d.king@lancaster.ac.uk>";

description
  "This module provides a YANG data model for the routing and
  wavelength assignment (RWA) Traffic Engineering (TE)
  topology in wavelength switched optical networks (WSNs).
  The YANG model described in this document is a WSON
  technology-specific YANG model augmenting the generic TE
  topology module (ietf-te-topology) based on the information
  model developed in RFC 7446 and the two encoding documents
  RFC 7579 and RFC 7581.

  Copyright (c) 2020 IETF Trust and the persons identified
  as authors of the code. All rights reserved.

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  BSD License set forth in Section 4.c of the IETF Trust's
  Legal Provisions Relating to IETF Documents
  (http://trustee.ietf.org/license-info).

  This version of this YANG module is part of RFC XXXX; see
  the RFC itself for full legal notices.";

revision 2020-10-16 {
  description
    "Initial Version";
  reference
    "RFC XXXX: A YANG Data Model for WSON (Wavelength Switched
```

```
    Optical Networks)";
    // RFC Ed.: replace XXXX with actual RFC number, update date
    // information and remove this note
}

/*
 * Data nodes
 */

augment "/nw:networks/nw:network/nw:network-types"
  + "/tet:te-topology" {
  description
    "Augment network types to define WSON topology type.";
  container wson-topology {
    presence
      "Its presence identifies the WSON topology type.";
    description
      "Introduce new network type for WSON topology.";
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te"
  + "/tet:te-node-attributes" {
  when "/nw:networks/nw:network/nw:network-types"
    + "/tet:te-topology/wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description "Augment TE node attributes.";
  container wson-node {
    presence "The TE node is a WSON node.";
    description "WSON node attributes";
    leaf is-reconfigurable-node {
      type boolean;
      default true;
      description
        "Indicates whether the WSON node is reconfigurable:
        - true: the node is reconfigurable, i.e.,
          it is representing a ROADM node;
        - false: the node is not reconfigurable, i.e.,
          it is representing a FOADM node.";
    }
  }
}

/*
 * Augment TE label range information
```

```

*/

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:label-restrictions/tet:label-restriction" {
  when "../..../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label range information for the TE node
    connectivity matrices.";
  uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction" {
  when "../..../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label range information for the source LTP
    of the connectivity matrix entry.";
  uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction" {
  when "../..../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label range information for the destination LTP
    of the connectivity matrix entry.";
  uses l0-types:l0-label-range-info;
}

```



```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the TE node
  connectivity matrices information source.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the source LTP
  of the connectivity matrix entry information source.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the destination LTP
  of the connectivity matrix entry information source.";
uses l0-types:l0-label-range-info;
}

```

```
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range information for the TTP
      Local Link Connectivities.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range information for the TTP
      Local Link Connectivity entry.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range information for the TE link.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
```

```
+ "tet:information-source-entry/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range information for the TE link
      information source.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction" {
description
    "Augment TE label range information for the TE link template.";
uses l0-types:l0-label-range-info;
}

/*
 * Augment TE label
 */

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range start for the TE node
      connectivity matrices";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/"
```

```
+ "tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range end for the TE node
      connectivity matrices";
case wson {
uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-step/"
+ "tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range step for the TE node
      connectivity matrices";
case wson {
uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
```

```

    "Augment TE label hop for the underlay primary path of the
      TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:backup-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path of the
      TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-exclude-objects/"
+ "tet:route-object-exclude-object/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
      by the path computation of the TE node connectivity
      matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

```

```

    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/"
    + "tet:type/tet:label/tet:label-hop/"
    + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects included
     by the path computation of the TE node connectivity
     matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:path-properties/tet:path-route-objects/"
  + "tet:path-route-object/tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the computed path route objects
     of the TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range start for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range end for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology" {
when "../.../.../.../.../.../.../.../.../..."

```

```

    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label range step for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:to/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label range start for the destination LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:to/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
}

```



```

    description
      "Augment TE label range end for the destination LTP
      of the connectivity matrix entry.";
    case wson {
      uses 10-types:wson-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry.";
case wson {
  uses 10-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the connectivity matrix entry.";
case wson {
  uses 10-types:wson-label-hop;
}
}

```

```

}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:backup-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the connectivity matrix entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"
  + "tet:algorithm/tet:metric/tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the explicit route objects excluded
  by the path computation of the connectivity matrix entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"

```

```

    + "tet:algorithm/tet:metric/tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSOON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSOON topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
              WSON topology type.";
    }
    description
        "Augment TE label range start for the TE node connectivity
          matrices information source.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
              WSON topology type.";
    }
    description
        "Augment TE label range end for the TE node connectivity
          matrices information source.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-step/tet:technology" {
    when "../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
              WSON topology type.";
    }
    description
        "Augment TE label range step for the TE node connectivity
          matrices information source.";
    case wson {

```

```

    uses l0-types:wson-label-step;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay primary path
     of the TE node connectivity matrices of the information
     source entry.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path
     of the TE node connectivity matrices of the information
     source entry.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```

```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TE node connectivity matrices
    information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TE node connectivity matrices
    information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."

```

```

    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the TE node connectivity matrices information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:from/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range start for the source LTP
    of the connectivity matrix entry information source.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:from/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description

```

```

        "Augment TE label range end for the source LTP
        of the connectivity matrix entry information source.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:from/tet:label-restrictions/"
+ "tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range step for the source LTP
    of the connectivity matrix entry information source.";
case wson {
    uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:to/tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range start for the destination LTP
    of the connectivity matrix entry information source.";
case wson {
    uses l0-types:wson-label-start-end;
}
}
}

```



```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range end for the destination LTP
  of the connectivity matrix entry information source.";
case wson {
  uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry information source.";
case wson {
  uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the connectivity matrix entry information source.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the connectivity matrix entry information source.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description

```

```

    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the connectivity matrix entry
    information source.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the connectivity matrix entry
  information source.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the connectivity matrix entry information source.";

```

```

    case wson {
      uses 10-types:wson-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range start for the TTP
  Local Link Connectivities.";
case wson {
  uses 10-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology"{
when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range end for the TTP
  Local Link Connectivities.";
case wson {
  uses 10-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology"{
when "../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range step for the TTP
        Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-step;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../..../..../..../..../..../..../..../..../"
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects excluded
        by the path computation of the TTP Local Link
        Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../..../..../..../..../..../..../..../..../"
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description

```

```

        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects included
        by the path computation of the TTP Local Link
        Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the computed path route objects
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range start for the TTP

```

```

        Local Link Connectivity entry.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range end for the TTP
    Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range step for the TTP
    Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-step;
}
}

```



```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the TTP Local Link Connectivity entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the TTP Local Link Connectivity entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```

```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TTP Local Link
    Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"

```

```

    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the TTP Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}
augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the underlay primary path
    of the TE link.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description

```

```

    "Augment TE label hop for the underlay backup path
      of the TE link.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label range start for the TE link.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label range end for the TE link.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description

```

```

        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range step for the TE link.";
    case wson {
        uses 10-types:wson-label-step;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../..//../..//../..//nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range start for the TE link
        information source.";
    case wson {
        uses 10-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    when "../..//../..//../..//nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range end for the TE link
        information source.";
    case wson {
        uses 10-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"

```

```

+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range step for the TE link
      information source.";
case wson {
    uses l0-types:wson-label-step;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
description
    "Augment TE label hop for the underlay primary path
      of the TE link template.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
description
    "Augment TE label hop for the underlay backup path
      of the TE link template.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
description
    "Augment TE label range start for the TE link template.";
case wson {
    uses l0-types:wson-label-start-end;

```

```

    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    description
      "Augment TE label range end for the TE link template.";
    case wson {
      uses l0-types:wson-label-start-end;
    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/tet:technology" {
    description
      "Augment TE label range step for the TE link template.";
    case wson {
      uses l0-types:wson-label-step;
    }
  }
}

<CODE ENDS>

```

4. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF Protocol over Secure Shell (SSH) [RFC6242] describes a method for invoking and running NETCONF within a Secure Shell (SSH) session as an SSH subsystem. The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the

default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

5. IANA Considerations

It is proposed to IANA to assign new URIs from the "IETF XML Registry" [RFC3688] as follows:

```
URI: urn:ietf:params:xml:ns:yang:ietf-wson-topology
Registrant Contact: The IESG
XML: N/A; the requested URI is an XML namespace.
```

This document registers a YANG module in the YANG Module Names registry [RFC7950] and [RFC6020].

```
name:      ietf-wson-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-wson-topology
prefix:    wson
reference:  RFC XXXX
```

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Framework for Abstraction and Control of Traffic Engineered Networks
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Abstract

Traffic Engineered networks have a variety of mechanisms to facilitate the separation of the data plane and control plane. They also have a range of management and provisioning protocols to configure and activate network resources. These mechanisms represent key technologies for enabling flexible and dynamic networking. The term "Traffic Engineered network" refers to a network that uses any connection-oriented technology under the control of a distributed or centralized control plane to support dynamic provisioning of end-to-end connectivity.

Abstraction of network resources is a technique that can be applied to a single network domain or across multiple domains to create a single virtualized network that is under the control of a network operator or the customer of the operator that actually owns the network resources.

This document provides a framework for Abstraction and Control of Traffic Engineered Networks (ACTN) to support virtual network services and connectivity services.

Status of this Memo

This Internet-Draft is submitted to IETF in full conformance with the provisions of BCP 78 and BCP 79.

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1. Introduction

The term "Traffic Engineered network" refers to a network that uses any connection-oriented technology under the control of a distributed or centralized control plane to support dynamic provisioning of end-to-end connectivity. Traffic Engineered (TE) networks have a variety of mechanisms to facilitate the separation of data plane and control plane including distributed signaling for path setup and protection, centralized path computation for planning and traffic engineering, and a range of management and provisioning protocols to configure and activate network resources. These mechanisms represent key technologies for enabling flexible and dynamic networking. Some examples of networks that are in scope of this definition are optical networks, Multiprotocol Label Switching (MPLS) Transport Profile (MPLS-TP) networks [RFC5654], and MPLS-TE networks [RFC2702].

One of the main drivers for Software Defined Networking (SDN) [RFC7149] is a decoupling of the network control plane from the data

plane. This separation has been achieved for TE networks with the development of MPLS/GMPLS [RFC3945] and the Path Computation Element (PCE) [RFC4655]. One of the advantages of SDN is its logically centralized control regime that allows a global view of the underlying networks. Centralized control in SDN helps improve network resource utilization compared with distributed network control. For TE-based networks, a PCE may serve as a logically centralized path computation function.

This document describes a set of management and control functions used to operate one or more TE networks to construct virtual networks that can be presented to customers and that are built from abstractions of the underlying TE networks. For example, a link in the customer's network is constructed from a path or collection of paths in the underlying networks. We call this set of functions "Abstraction and Control of Traffic Engineered Networks" (ACTN).

2. Overview

Three key aspects that need to be solved by SDN are:

- . Separation of service requests from service delivery so that the configuration and operation of a network is transparent from the point of view of the customer, but remains responsive to the customer's services and business needs.
- . Network abstraction: As described in [RFC7926], abstraction is the process of applying policy to a set of information about a TE network to produce selective information that represents the potential ability to connect across the network. The process of abstraction presents the connectivity graph in a way that is independent of the underlying network technologies, capabilities, and topology so that the graph can be used to plan and deliver network services in a uniform way
- . Coordination of resources across multiple independent networks and multiple technology layers to provide end-to-end services regardless of whether the networks use SDN or not.

As networks evolve, the need to provide support for distinct services, separated service orchestration, and resource abstraction have emerged as key requirements for operators. In order to support multiple customers each with its own view of and control of the server network, a network operator needs to partition (or "slice") or manage sharing of the network resources. Network slices can be assigned to each customer for guaranteed usage which is a step further than shared use of common network resources.

Furthermore, each network represented to a customer can be built from virtualization of the underlying networks so that, for example, a link in the customer's network is constructed from a path or collection of paths in the underlying network.

ACTN can facilitate virtual network operation via the creation of a single virtualized network or a seamless service. This supports operators in viewing and controlling different domains (at any dimension: applied technology, administrative zones, or vendor-specific technology islands) and presenting virtualized networks to their customers.

The ACTN framework described in this document facilitates:

- . Abstraction of the underlying network resources to higher-layer applications and customers [RFC7926].
- . Virtualization of particular underlying resources, whose selection criterion is the allocation of those resources to a particular customer, application, or service [ONF-ARCH].
- . TE Network slicing of infrastructure to meet specific customers' service requirements.
- . Creation of an abstract environment allowing operators to view and control multi-domain networks as a single abstract network.
- . The presentation to customers of networks as a virtual network via open and programmable interfaces.

2.1. Terminology

The following terms are used in this document. Some of them are newly defined, some others reference existing definitions:

- . Domain: A domain [RFC4655] is any collection of network elements within a common sphere of address management or path computation responsibility. Specifically within this document we mean a part of an operator's network that is under common management (i.e., under shared operational management using the same instances of a tool and the same policies). Network elements will often be grouped into domains based on technology types, vendor profiles, and geographic proximity.
- . Abstraction: This process is defined in [RFC7926].

- . TE Network Slicing: In the context of ACTN, a TE network slice is a collection of resources that is used to establish a logically dedicated virtual network over one or more TE networks. TE network slicing allows a network operator to provide dedicated virtual networks for applications/customers over a common network infrastructure. The logically dedicated resources are a part of the larger common network infrastructures that are shared among various TE network slice instances which are the end-to-end realization of TE network slicing, consisting of the combination of physically or logically dedicated resources.
- . Node: A node is a vertex on the graph representation of a TE topology. In a physical network topology, a node corresponds to a physical network element (NE) such as a router. In an abstract network topology, a node (sometimes called an abstract node) is a representation as a single vertex of one or more physical NEs and their connecting physical connections. The concept of a node represents the ability to connect from any access to the node (a link end) to any other access to that node, although "limited cross-connect capabilities" may also be defined to restrict this functionality. Network abstraction may be applied recursively, so a node in one topology may be created by applying abstraction to the nodes in the underlying topology.
- . Link: A link is an edge on the graph representation of a TE topology. Two nodes connected by a link are said to be "adjacent" in the TE topology. In a physical network topology, a link corresponds to a physical connection. In an abstract network topology, a link (sometimes called an abstract link) is a representation of the potential to connect a pair of points with certain TE parameters (see [RFC7926] for details). Network abstraction may be applied recursively, so a link in one topology may be created by applying abstraction to the links in the underlying topology.
- . Abstract Topology: The topology of abstract nodes and abstract links presented through the process of abstraction by a lower layer network for use by a higher layer network.
- . A Virtual Network (VN) is a network provided by a service provider to a customer for the customer to use in any way it wants as though it was a physical network. There are two views of a VN as follows:

- a) The VN can be abstracted as a set of edge-to-edge links (a Type 1 VN). Each link is referred as a VN member and is formed as an end-to-end tunnel across the underlying networks. Such tunnels may be constructed by recursive slicing or abstraction of paths in the underlying networks and can encompass edge points of the customer's network, access links, intra-domain paths, and inter-domain links.
- b) The VN can also be abstracted as a topology of virtual nodes and virtual links (a Type 2 VN). The operator needs to map the VN to actual resource assignment, which is known as virtual network embedding. The nodes in this case include physical end points, border nodes, and internal nodes as well as abstracted nodes. Similarly the links include physical access links, inter-domain links, and intra-domain links as well as abstract links.

Clearly a Type 1 VN is a special case of a Type 2 VN.

- . Access link: A link between a customer node and a operator node.
- . Inter-domain link: A link between domains under distinct management administration.
- . Access Point (AP): An AP is a logical identifier shared between the customer and the operator used to identify an access link. The AP is used by the customer when requesting a VNS. Note that the term "TE Link Termination Point" (LTP) defined in [TE-Topo] describes the end points of links, while an AP is a common identifier for the link itself.
- . VN Access Point (VNAP): A VNAP is the binding between an AP and a given VN.
- . Server Network: As defined in [RFC7926], a server network is a network that provides connectivity for another network (the Client Network) in a client-server relationship.

2.2. VNS Model of ACTN

A Virtual Network Service (VNS) is the service agreement between a customer and operator to provide a VN. When a VN is a simple connectivity between two points, the difference between VNS and connectivity service becomes blurred. There are three types of VNS defined in this document.

- o Type 1 VNS refers to a VNS in which the customer is allowed to create and operate a Type 1 VN.
- o Type 2a and 2b VNS refer to VNSs in which the customer is allowed to create and operates a Type 2 VN. With a Type 2a VNS, the VN is statically created at service configuration time and the customer is not allowed to change the topology (e.g., by adding or deleting abstract nodes and links). A Type 2b VNS is the same as a Type 2a VNS except that the customer is allowed to make dynamic changes to the initial topology created at service configuration time.

VN Operations are functions that a customer can exercise on a VN depending on the agreement between the customer and the operator.

- o VN Creation allows a customer to request the instantiation of a VN. This could be through off-line pre-configuration or through dynamic requests specifying attributes to a Service Level Agreement (SLA) to satisfy the customer's objectives.
- o Dynamic Operations allow a customer to modify or delete the VN. The customer can further act upon the virtual network to create/modify/delete virtual links and nodes. These changes will result in subsequent tunnel management in the operator's networks.

There are three key entities in the ACTN VNS model:

- Customers
- Service Providers
- Network Operators

These entities are related in a three tier model as shown in Figure 1.

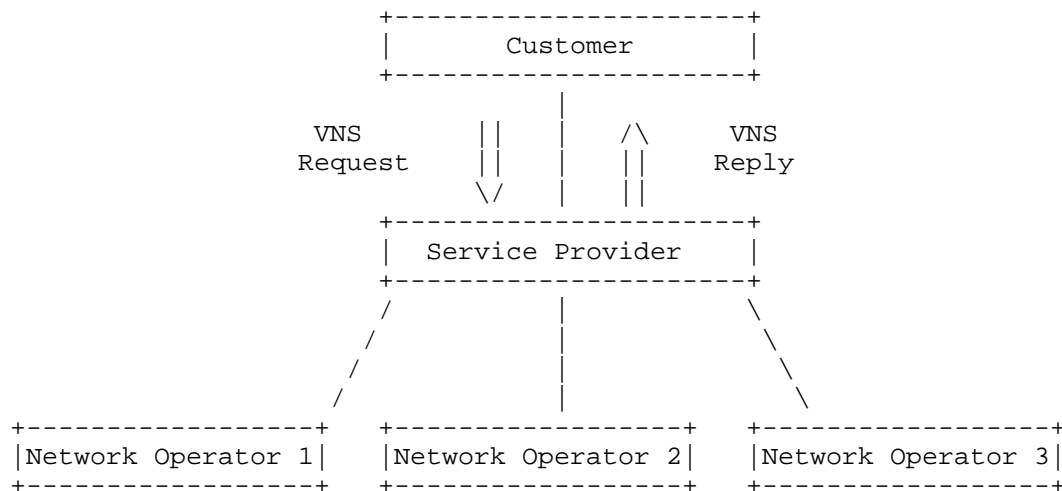


Figure 1: The Three Tier Model.

The commercial roles of these entities are described in the following sections.

2.2.1. Customers

Basic customers include fixed residential users, mobile users, and small enterprises. Each requires a small amount of resources and is characterized by steady requests (relatively time invariant). Basic customers do not modify their services themselves: if a service change is needed, it is performed by the provider as a proxy.

Advanced customers include enterprises and governments. Such customers ask for both point-to point and multipoint connectivity with high resource demands varying significantly in time. This is one of the reasons why a bundled service offering is not enough and it is desirable to provide each advanced customer with a customized virtual network service. Advanced customers may also have the ability to modify their service parameters within the scope of their virtualized environments. The primary focus of ACTN is Advanced Customers.

As customers are geographically spread over multiple network operator domains, they have to interface to multiple operators and may have to support multiple virtual network services with different underlying objectives set by the network operators. To enable these

customers to support flexible and dynamic applications they need to control their allocated virtual network resources in a dynamic fashion, and that means that they need a view of the topology that spans all of the network operators. Customers of a given service provider can in turn offer a service to other customers in a recursive way.

2.2.2. Service Providers

In the scope of ACTN, service providers deliver VNSs to their customers. Service providers may or may not own physical network resources (i.e., may or may not be network operators as described in Section 2.2.3). When a service provider is the same as the network operator, this is similar to existing VPN models applied to a single operator although it may be hard to use this approach when the customer spans multiple independent network operator domains.

When network operators supply only infrastructure, while distinct service providers interface to the customers, the service providers are themselves customers of the network infrastructure operators. One service provider may need to keep multiple independent network operators because its end-users span geographically across multiple network operator domains. In some cases, service provider is also a network operator when it owns network infrastructure on which service is provided.

2.2.3. Network Operators

Network operators are the infrastructure operators that provision the network resources and provide network resources to their customers. The layered model described in this architecture separates the concerns of network operators and customers, with service providers acting as aggregators of customer requests.

3. ACTN Base Architecture

This section provides a high-level model of ACTN showing the interfaces and the flow of control between components.

The ACTN architecture is based on a 3-tier reference model and allows for hierarchy and recursion. The main functionalities within an ACTN system are:

- . Multi-domain coordination: This function oversees the specific aspects of different domains and builds a single abstracted end-to-end network topology in order to coordinate end-to-end path computation and path/service provisioning. Domain

sequence path calculation/determination is also a part of this function.

- . Abstraction: This function provides an abstracted view of the underlying network resources for use by the customer - a customer may be the client or a higher level controller entity. This function includes network path computation based on customer service connectivity request constraints, path computation based on the global network-wide abstracted topology, and the creation of an abstracted view of network resources allocated to each customer. These operations depend on customer-specific network objective functions and customer traffic profiles.
- . Customer mapping/translation: This function is to map customer requests/commands into network provisioning requests that can be sent from the Multi-Domain Service Coordinator (MDSC) to the Provisioning Network Controller (PNC) according to business policies provisioned statically or dynamically at the Operations Support System (OSS)/ Network Management System (NMS). Specifically, it provides mapping and translation of a customer's service request into a set of parameters that are specific to a network type and technology such that network configuration process is made possible.
- . Virtual service coordination: This function translates customer service-related information into virtual network service operations in order to seamlessly operate virtual networks while meeting a customer's service requirements. In the context of ACTN, service/virtual service coordination includes a number of service orchestration functions such as multi-destination load balancing, guarantees of service quality, bandwidth and throughput. It also includes notifications for service fault and performance degradation and so forth.

The base ACTN architecture defines three controller types and the corresponding interfaces between these controllers. The following types of controller are shown in Figure 2:

- . CNC - Customer Network Controller
- . MDSC - Multi-Domain Service Coordinator
- . PNC - Provisioning Network Controller

Figure 2 also shows the following interfaces:

- . CMI - CNC-MDSC Interface
- . MPI - MDSC-PNC Interface

. SBI - Southbound Interface

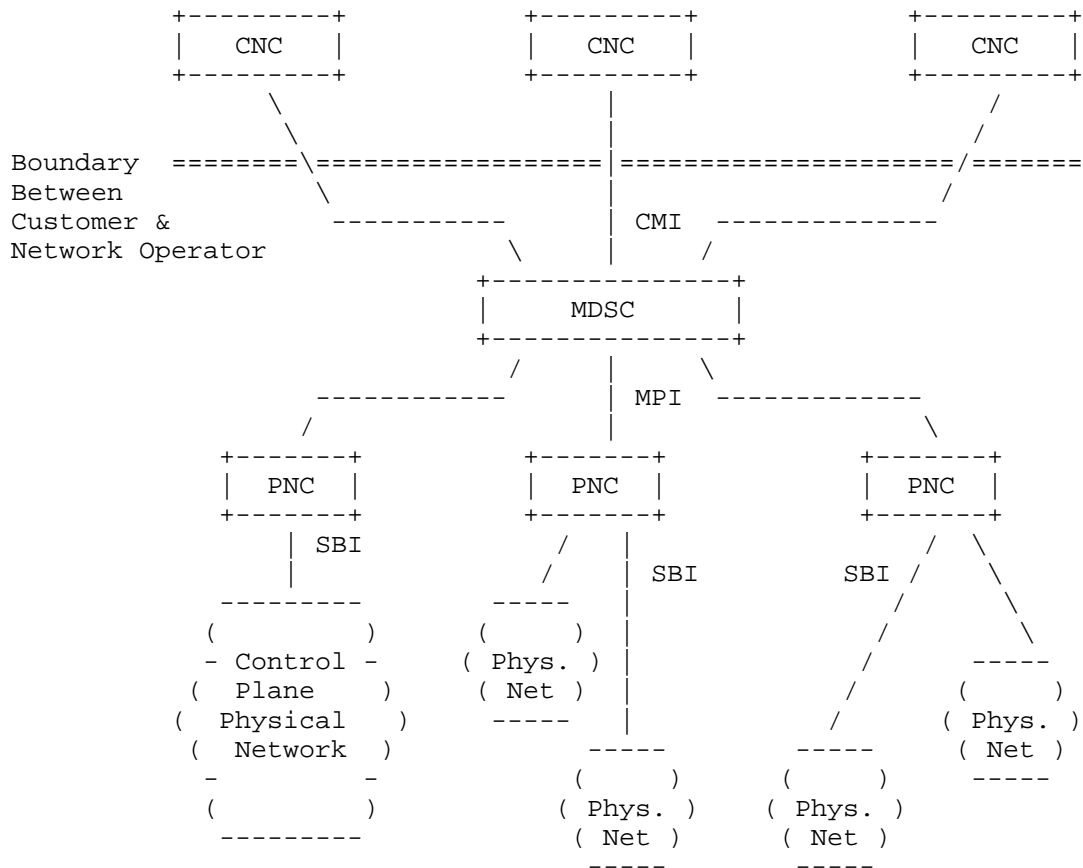


Figure 2: ACTN Base Architecture

Note that this is a functional architecture: an implementation and deployment might collocate one or more of the functional components. Figure 2 shows a case where service provider is also a network operator.

3.1. Customer Network Controller

A Customer Network Controller (CNC) is responsible for communicating a customer's VNS requirements to the network operator over the CNC-MDSC Interface (CMI). It has knowledge of the end-points associated

with the VNS (expressed as APs), the service policy, and other QoS information related to the service.

As the Customer Network Controller directly interfaces to the applications, it understands multiple application requirements and their service needs. The capability of a CNC beyond its CMI role is outside the scope of ACTN and may be implemented in different ways. For example, the CNC may in fact be a controller or part of a controller in the customer's domain, or the CNC functionality could also be implemented as part of a service provider's portal.

3.2. Multi-Domain Service Coordinator

A Multi-Domain Service Coordinator (MDSC) is a functional block that implements all of the ACTN functions listed in Section 3 and described further in Section 4.2. Two functions of the MDSC, namely, multi-domain coordination and virtualization/abstraction are referred to as network-related functions while the other two functions, namely, customer mapping/translation and virtual service coordination are referred to as service-related functions. The MDSC sits at the center of the ACTN model between the CNC that issues connectivity requests and the Provisioning Network Controllers (PNCs) that manage the network resources.

The key point of the MDSC (and of the whole ACTN framework) is detaching the network and service control from underlying technology to help the customer express the network as desired by business needs. The MDSC envelopes the instantiation of the right technology and network control to meet business criteria. In essence it controls and manages the primitives to achieve functionalities as desired by the CNC.

In order to allow for multi-domain coordination a 1:N relationship must be allowed between MDSCs and PNCs.

In addition to that, it could also be possible to have an M:1 relationship between MDSCs and PNC to allow for network resource partitioning/sharing among different customers not necessarily connected to the same MDSC (e.g., different service providers) but all using the resources of a common network infrastructure operator.

3.3. Provisioning Network Controller

The Provisioning Network Controller (PNC) oversees configuring the network elements, monitoring the topology (physical or virtual) of

the network, and collecting information about the topology (either raw or abstracted).

The PNC functions can be implemented as part of an SDN domain controller, a Network Management System (NMS), an Element Management System (EMS), an active PCE-based controller [Centralized] or any other means to dynamically control a set of nodes and implementing a north bound interface from the standpoint of the nodes (which is out of the scope of this document). A PNC domain includes all the resources under the control of a single PNC. It can be composed of different routing domains and administrative domains, and the resources may come from different layers. The interconnection between PNC domains is illustrated in Figure 3.

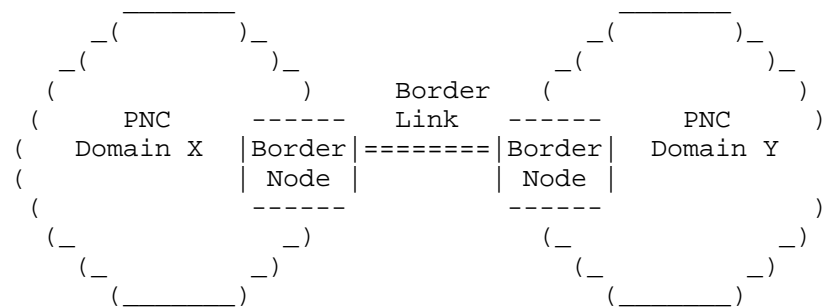


Figure 3: PNC Domain Borders

3.4. ACTN Interfaces

Direct customer control of transport network elements and virtualized services is not a viable proposition for network operators due to security and policy concerns. Therefore, the network has to provide open, programmable interfaces, through which customer applications can create, replace and modify virtual network resources and services in an interactive, flexible and dynamic fashion.

Three interfaces exist in the ACTN architecture as shown in Figure 2.

- . CMI: The CNC-MDSC Interface (CMI) is an interface between a CNC and an MDSC. The CMI is a business boundary between customer and network operator. It is used to request a VNS for an application. All service-related information is conveyed over this interface (such as the VNS type, topology, bandwidth, and

service constraints). Most of the information over this interface is agnostic of the technology used by network operators, but there are some cases (e.g., access link configuration) where it is necessary to specify technology-specific details.

- . MPI: The MDSC-PNC Interface (MPI) is an interface between an MDSC and a PNC. It communicates requests for new connectivity or for bandwidth changes in the physical network. In multi-domain environments, the MDSC needs to communicate with multiple PNCs each responsible for control of a domain. The MPI presents an abstracted topology to the MDSC hiding technology specific aspects of the network and hiding topology according to policy.
- . SBI: The Southbound Interface (SBI) is out of scope of ACTN. Many different SBIs have been defined for different environments, technologies, standards organizations, and vendors. It is shown in Figure 3 for reference reason only.

4. Advanced ACTN Architectures

This section describes advanced configurations of the ACTN architecture.

4.1. MDSC Hierarchy

A hierarchy of MDSCs can be foreseen for many reasons, among which are scalability, administrative choices, or putting together different layers and technologies in the network. In the case where there is a hierarchy of MDSCs, we introduce the terms higher-level MDSC (MDSC-H) and lower-level MDSC (MDSC-L). The interface between them is a recursion of the MPI. An implementation of an MDSC-H makes provisioning requests as normal using the MPI, but an MDSC-L must be able to receive requests as normal at the CMI and also at the MPI. The hierarchy of MDSCs can be seen in Figure 4.

Another implementation choice could foresee the usage of an MDSC-L for all the PNCs related to a given technology (e.g., Internet Protocol (IP)/Multiprotocol Label Switching (MPLS)) and a different MDSC-L for the PNCs related to another technology (e.g., Optical Transport Network (OTN)/Wavelength Division Multiplexing (WDM)) and an MDSC-H to coordinate them.

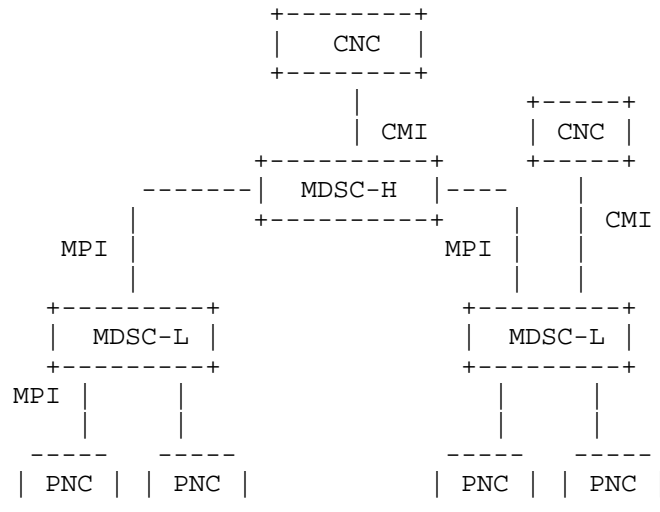
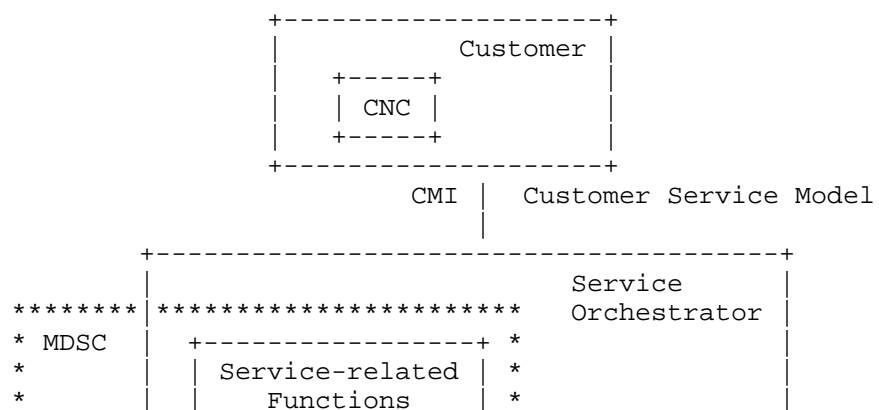


Figure 4: MDSC Hierarchy

The hierarchy of MDSC can be recursive, where an MDSC-H is in turn an MDSC-L to a higher level MDSC-H.

4.2. Functional Split of MDSC Functions in Orchestrators

An implementation choice could separate the MDSC functions into two groups, one group for service-related functions and the other for network-related functions. This enables the implementation of a service orchestrator that provides the service-related functions of the MDSC and a network orchestrator that provides the network-related functions of the MDSC. This split is consistent with the Yet Another Next Generation (YANG) service model architecture described in [Service-YANG]. Figure 5 depicts this and shows how the ACTN interfaces may map to YANG models.



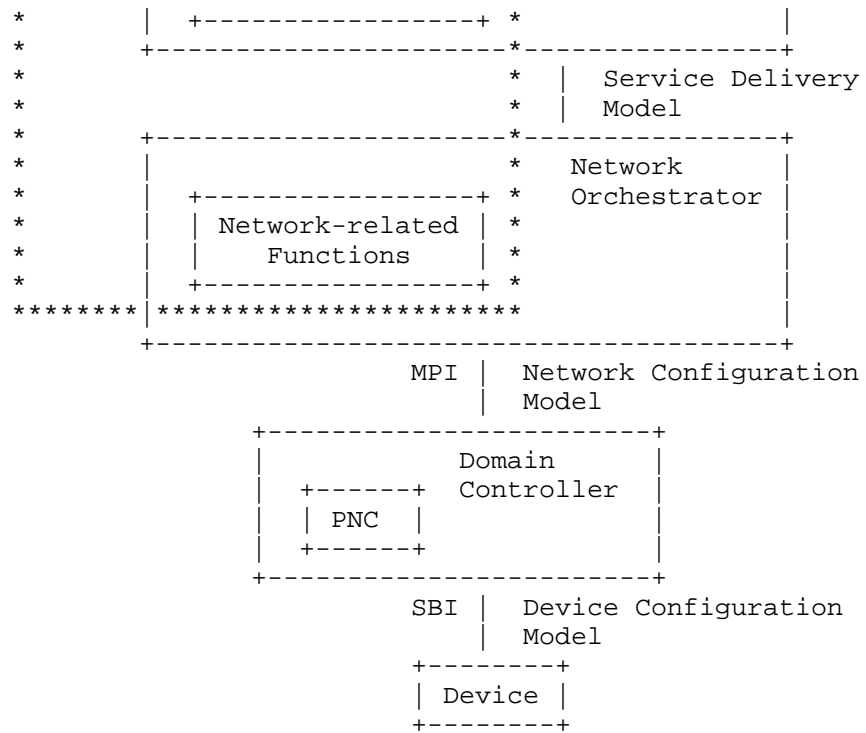


Figure 5: ACTN Architecture in the Context of the YANG Service Models

5. Topology Abstraction Methods

Topology abstraction is described in [RFC7926]. This section discusses topology abstraction factors, types, and their context in the ACTN architecture.

Abstraction in ACTN is performed by the PNC when presenting available topology to the MDSC, or by an MDSC-L when presenting topology to an MDSC-H. This function is different to the creation of a VN (and particularly a Type 2 VN) which is not abstraction but construction of virtual resources.

5.1. Abstraction Factors

As discussed in [RFC7926], abstraction is tied with policy of the networks. For instance, per an operational policy, the PNC would not provide any technology specific details (e.g., optical parameters for Wavelength Switched Optical Network (WSO) in the abstract topology it provides to the MDSC. Similarly, policy of the

networks may determine the abstraction type as described in Section 5.2.

There are many factors that may impact the choice of abstraction:

- Abstraction depends on the nature of the underlying domain networks. For instance, packet networks may be abstracted with fine granularity while abstraction of optical networks depends on the switching units (such as wavelengths) and the end-to-end continuity and cross-connect limitations within the network.
- Abstraction also depends on the capability of the PNCs. As abstraction requires hiding details of the underlying network resources, the PNC's capability to run algorithms impacts the feasibility of abstraction. Some PNC may not have the ability to abstract native topology while other PNCs may have the ability to use sophisticated algorithms.
- Abstraction is a tool that can improve scalability. Where the native network resource information is of large size there is a specific scaling benefit to abstraction.
- The proper abstraction level may depend on the frequency of topology updates and vice versa.
- The nature of the MDSC's support for technology-specific parameters impacts the degree/level of abstraction. If the MDSC is not capable of handling such parameters then a higher level of abstraction is needed.
- In some cases, the PNC is required to hide key internal topological data from the MDSC. Such confidentiality can be achieved through abstraction.

5.2. Abstraction Types

This section defines the following three types of topology abstraction:

- . Native/White Topology (Section 5.2.1)
- . Black Topology (Section 5.2.2)
- . Grey Topology (Section 5.2.3)

5.2.1. Native/White Topology

This is a case where the PNC provides the actual network topology to the MDSC without any hiding or filtering of information, i.e., no

abstraction is performed. In this case, the MDSC has the full knowledge of the underlying network topology and can operate on it directly.

5.2.2. Black Topology

A black topology replaces a full network with a minimal representation of the edge-to-edge topology without disclosing any node internal connectivity information. The entire domain network may be abstracted as a single abstract node with the network's access/egress links appearing as the ports to the abstract node and the implication that any port can be 'cross-connected' to any other. Figure 6 depicts a native topology with the corresponding black topology with one virtual node and inter-domain links. In this case, the MDSC has to make a provisioning request to the PNCs to establish the port-to-port connection. If there is a large number of inter-connected domains, this abstraction method may impose a heavy coordination load at the MDSC level in order to find an optimal end-to-end path since the abstraction hides so much information that it is not possible to determine whether an end-to-end path is feasible without asking each PNC to set up each path fragment. For this reason, the MPI might need to be enhanced to allow the PNCs to be queried for the practicality and characteristics of paths across the abstract node.

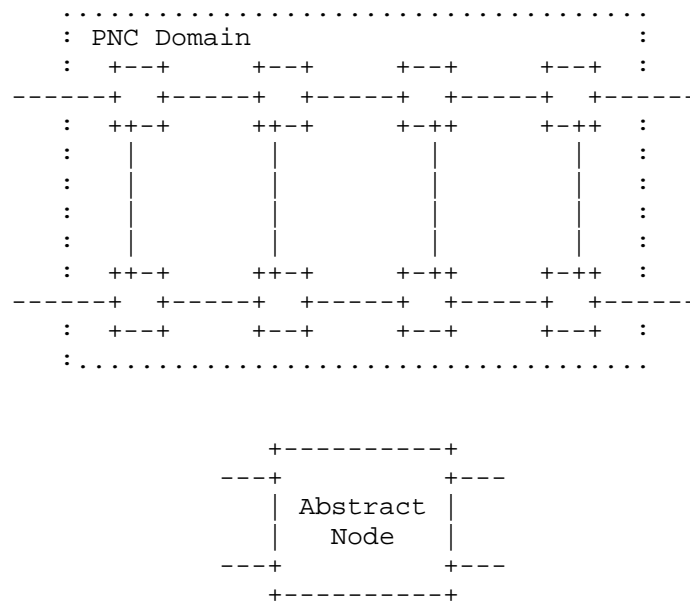


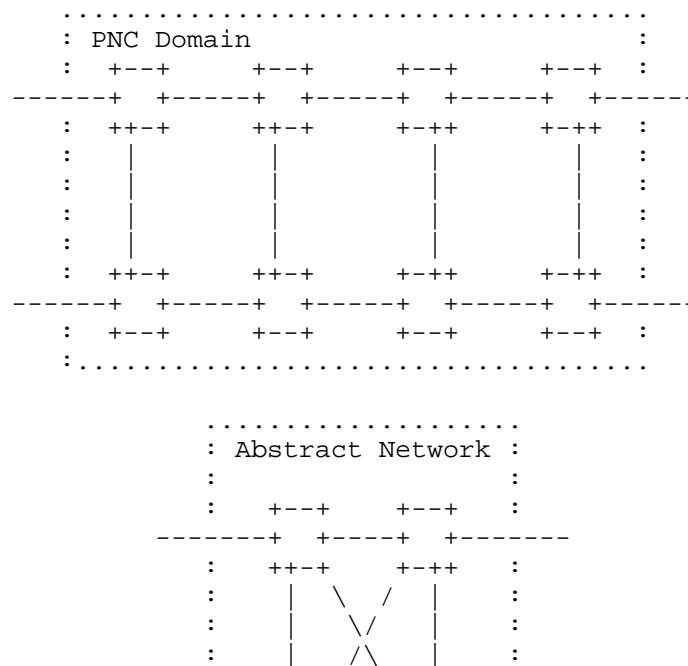
Figure 6: Native Topology with Corresponding Black Topology Expressed as an Abstract Node

5.2.3. Grey Topology

A grey topology represents a compromise between black and white topologies from a granularity point of view. In this case, the PNC exposes an abstract topology containing all PNC domains border nodes and an abstraction of the connectivity between those border nodes. This abstraction may contain either physical or abstract nodes/links.

Two types of grey topology are identified:

- . In a type A grey topology, border nodes are connected by a full mesh of TE links (see Figure 7).
- . In a type B grey topology, border nodes are connected over a more detailed network comprising internal abstract nodes and abstracted links. This mode of abstraction supplies the MDSC with more information about the internals of the PNC domain and allows it to make more informed choices about how to route connectivity over the underlying network.



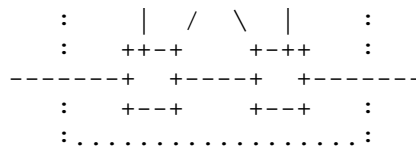


Figure 7: Native Topology with Corresponding Grey Topology

5.3. Methods of Building Grey Topologies

This section discusses two different methods of building a grey topology:

- . Automatic generation of abstract topology by configuration (Section 5.3.1)
- . On-demand generation of supplementary topology via path computation request/reply (Section 5.3.2)

5.3.1. Automatic Generation of Abstract Topology by Configuration

Automatic generation is based on the abstraction/summarization of the whole domain by the PNC and its advertisement on the MPI. The level of abstraction can be decided based on PNC configuration parameters (e.g., "provide the potential connectivity between any PE and any ASBR in an MPLS-TE network").

Note that the configuration parameters for this abstract topology can include available bandwidth, latency, or any combination of defined parameters. How to generate such information is beyond the scope of this document.

This abstract topology may need to be periodically or incrementally updated when there is a change in the underlying network or the use of the network resources that make connectivity more or less available.

5.3.2. On-demand Generation of Supplementary Topology via Path Compute Request/Reply

While abstract topology is generated and updated automatically by configuration as explained in Section 5.3.1, additional supplementary topology may be obtained by the MDSC via a path compute request/reply mechanism.

The abstract topology advertisements from PNCs give the MDSC the border node/link information for each domain. Under this scenario,

when the MDSC needs to create a new VN, the MDSC can issue path computation requests to PNCs with constraints matching the VN request as described in [ACTN-YANG]. An example is provided in Figure 8, where the MDSC is creating a P2P VN between AP1 and AP2. The MDSC could use two different inter-domain links to get from domain X to domain Y, but in order to choose the best end-to-end path it needs to know what domain X and Y can offer in terms of connectivity and constraints between the PE nodes and the border nodes.

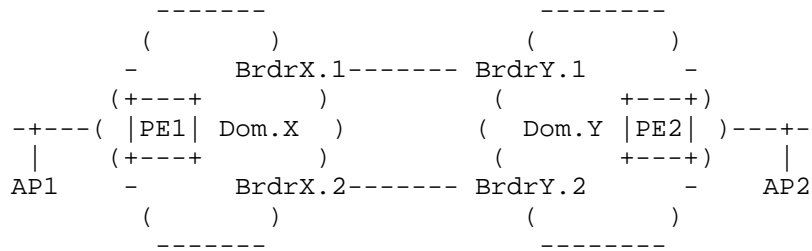
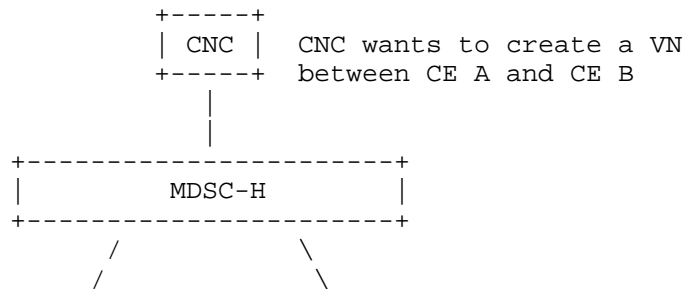


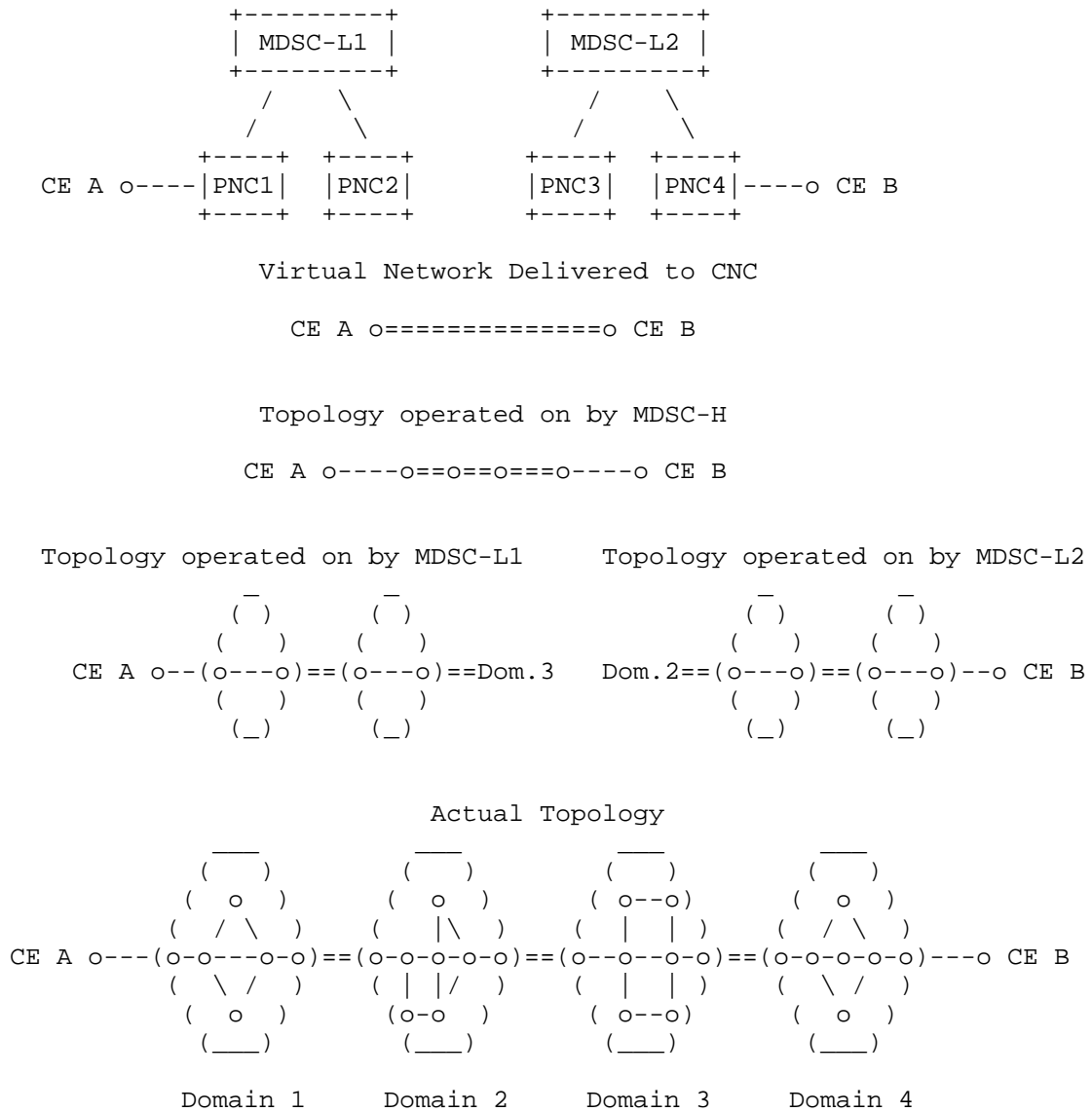
Figure 8: A Multi-Domain Example

The MDSC issues a path computation request to PNC.X asking for potential connectivity between PE1 and border node BrdrX.1 and between PE1 and BrdrX.2 with related objective functions and TE metric constraints. A similar request for connectivity from the border nodes in domain Y to PE2 will be issued to PNC.Y. The MDSC merges the results to compute the optimal end-to-end path including the inter domain links. The MDSC can use the result of this computation to request the PNCs to provision the underlying networks, and the MDSC can then use the end-to-end path as a virtual link in the VN it delivers to the customer.

5.4. Hierarchical Topology Abstraction Example

This section illustrates how topology abstraction operates in different levels of a hierarchy of MDSCs as shown in Figure 9.





Where

o is a node
 --- is a link
 === border link

Figure 9: Illustration of Hierarchical Topology Abstraction

In the example depicted in Figure 9, there are four domains under control of PNCs PNC1, PNC2, PNC3, and PNC4. MDSC-L1 controls PNC1

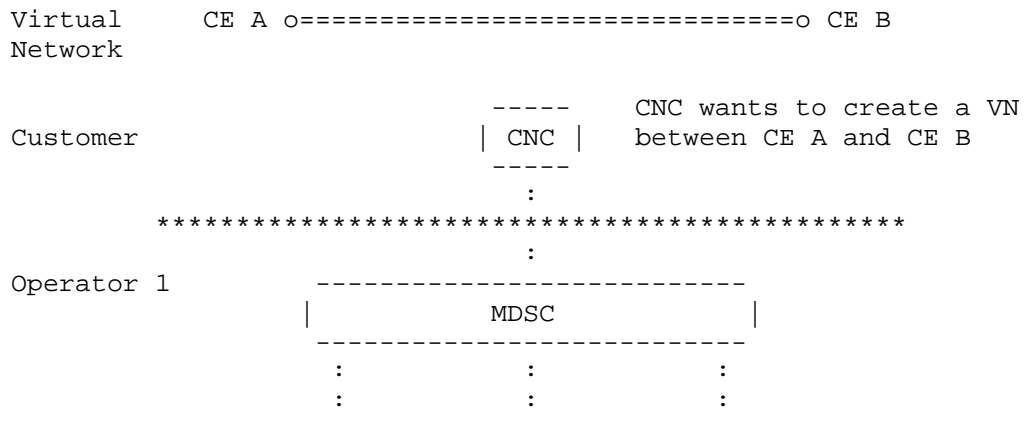
and PNC2 while MDSC-L2 controls PNC3 and PNC4. Each of the PNCs provides a grey topology abstraction that presents only border nodes and links across and outside the domain. The abstract topology MDSC-L1 that operates is a combination of the two topologies from PNC1 and PNC2. Likewise, the abstract topology that MDSC-L2 operates is shown in Figure 9. Both MDSC-L1 and MDSC-L2 provide a black topology abstraction to MDSC-H in which each PNC domain is presented as a single virtual node. MDSC-H combines these two topologies to create the abstraction topology on which it operates. MDSC-H sees the whole four domain networks as four virtual nodes connected via virtual links.

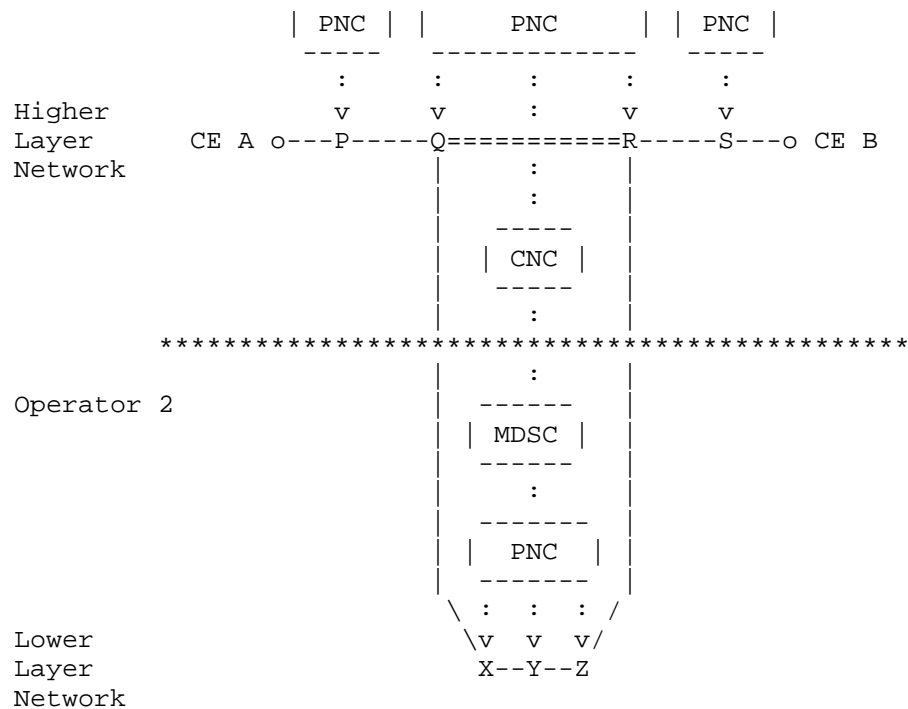
5.5. VN Recursion with Network Layers

In some cases the VN supplied to a customer may be built using resources from different technology layers operated by different operators. For example, one operator may run a packet TE network and use optical connectivity provided by another operator.

As shown in Figure 10, a customer asks for end-to-end connectivity between CE A and CE B, a virtual network. The customer's CNC makes a request to Operator 1's MDSC. The MDSC works out which network resources need to be configured and sends instructions to the appropriate PNCs. However, the link between Q and R is a virtual link supplied by Operator 2: Operator 1 is a customer of Operator 2.

To support this, Operator 1 has a CNC that communicates to Operator 2's MDSC. Note that Operator 1's CNC in Figure 10 is a functional component that does not dictate implementation: it may be embedded in a PNC.





Where

--- is a link

=== is a virtual link

Figure 10: VN recursion with Network Layers

6. Access Points and Virtual Network Access Points

In order to map identification of connections between the customer's sites and the TE networks and to scope the connectivity requested in the VNS, the CNC and the MDSC refer to the connections using the Access Point (AP) construct as shown in Figure 11.

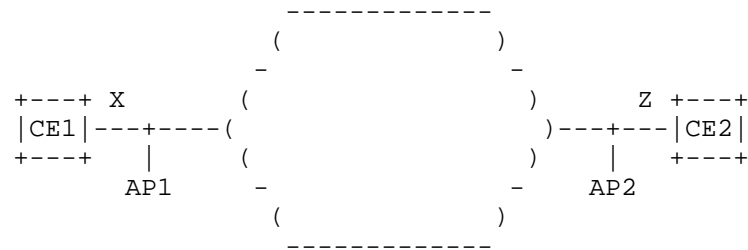


Figure 11: Customer View of APs

Let's take as an example a scenario shown in Figure 11. CE1 is connected to the network via a 10 Gbps link and CE2 via a 40 Gbps link. Before the creation of any VN between AP1 and AP2 the customer view can be summarized as shown in Table 1.

+-----+-----+			
End Point		Access Link Bandwidth	
+-----+-----+			
AP id	CE,port	MaxResBw	AvailableBw
+-----+-----+			
AP1	CE1,portX	10 Gbps	10 Gbps
+-----+-----+			
AP2	CE2,portZ	40 Gbps	40 Gbps
+-----+-----+			

Table 1: AP - Customer View

On the other hand, what the operator sees is shown in Figure 12.

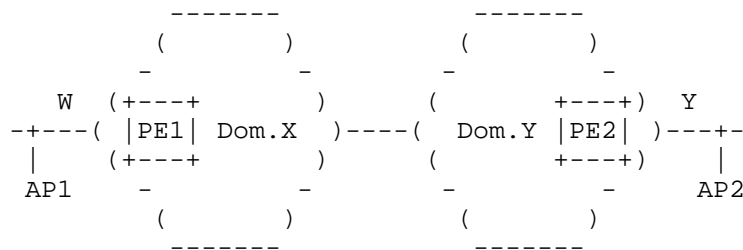


Figure 12: Operator view of the AP

Which results in a summarization as shown in Table 2.

End Point		Access Link Bandwidth	
AP id	PE,port	MaxResBw	AvailableBw
AP1	PE1,portW	10 Gbps	10 Gbps
AP2	PE2,portY	40 Gbps	40 Gbps

Table 2: AP - Operator View

A Virtual Network Access Point (VNAP) needs to be defined as binding between an AP and a VN. It is used to allow for different VNs to start from the same AP. It also allows for traffic engineering on the access and/or inter-domain links (e.g., keeping track of bandwidth allocation). A different VNAP is created on an AP for each VN.

In this simple scenario we suppose we want to create two virtual networks. The first with VN identifier 9 between AP1 and AP2 with bandwidth of 1 Gbps, while the second with VN identifier 5, again between AP1 and AP2 and with bandwidth 2 Gbps.

The operator view would evolve as shown in Table 3.

End Point		Access Link/VNAP Bw	
AP/VNAPid	PE,port	MaxResBw	AvailableBw
AP1	PE1,portW	10 Gbps	7 Gbps
-VNAP1.9		1 Gbps	N.A.
-VNAP1.5		2 Gbps	N.A.
AP2	PE2,portY	40 Gbps	37 Gbps
-VNAP2.9		1 Gbps	N.A.
-VNAP2.5		2 Gbps	N.A.

Table 3: AP and VNAP - Operator View after VNS Creation

6.1. Dual-Homing Scenario

Often there is a dual homing relationship between a CE and a pair of PEs. This case needs to be supported by the definition of VN, APs, and VNAPs. Suppose CE1 connected to two different PEs in the

operator domain via AP1 and AP2 and that the customer needs 5 Gbps of bandwidth between CE1 and CE2. This is shown in Figure 12.

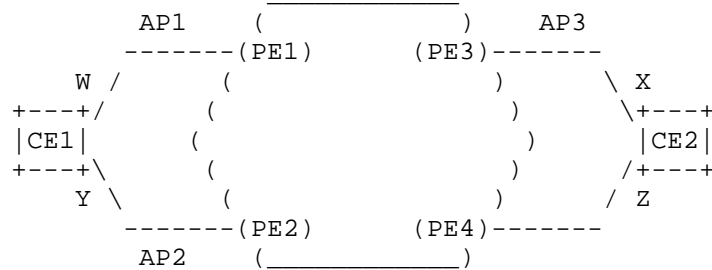


Figure 12: Dual-Homing Scenario

In this case, the customer will request for a VN between AP1, AP2, and AP3 specifying a dual homing relationship between AP1 and AP2. As a consequence no traffic will flow between AP1 and AP2. The dual homing relationship would then be mapped against the VNAPs (since other independent VNs might have AP1 and AP2 as end points).

The customer view would be shown in Table 4.

+-----+-----+-----+-----+-----+				
End Point		Access Link/VNAP Bw		
+-----+-----+-----+-----+-----+				
AP/VNAPid	CE, port	MaxResBw	AvailableBw	Dual Homing
+-----+-----+-----+-----+-----+				
AP1	CE1, portW	10 Gbps	5 Gbps	VNAP2.9
-VNAP1.9		5 Gbps	N.A.	
+-----+-----+-----+-----+-----+				
AP2	CE1, portY	40 Gbps	35 Gbps	VNAP1.9
-VNAP2.9		5 Gbps	N.A.	
+-----+-----+-----+-----+-----+				
AP3	CE2, portX	50 Gbps	45 Gbps	NONE
-VNAP3.9		5 Gbps	N.A.	
+-----+-----+-----+-----+-----+				

Table 4: Dual-Homing - Customer View after VN Creation

7. Advanced ACTN Application: Multi-Destination Service

A further advanced application of ACTN is in the case of Data Center selection, where the customer requires the Data Center selection to be based on the network status; this is referred to as Multi-Destination in [ACTN-REQ]. In terms of ACTN, a CNC could request a

VNS between a set of source APs and destination APs and leave it up to the network (MDSC) to decide which source and destination access points to be used to set up the VNS. The candidate list of source and destination APs is decided by a CNC (or an entity outside of ACTN) based on certain factors which are outside the scope of ACTN.

Based on the AP selection as determined and returned by the network (MDSC), the CNC (or an entity outside of ACTN) should further take care of any subsequent actions such as orchestration or service setup requirements. These further actions are outside the scope of ACTN.

Consider a case as shown in Figure 14, where three data centers are available, but the customer requires the data center selection to be based on the network status and the connectivity service setup between the AP1 (CE1) and one of the destination APs (AP2 (DC-A), AP3 (DC-B), and AP4 (DC-C)). The MDSC (in coordination with PNCs) would select the best destination AP based on the constraints, optimization criteria, policies, etc., and setup the connectivity service (virtual network).

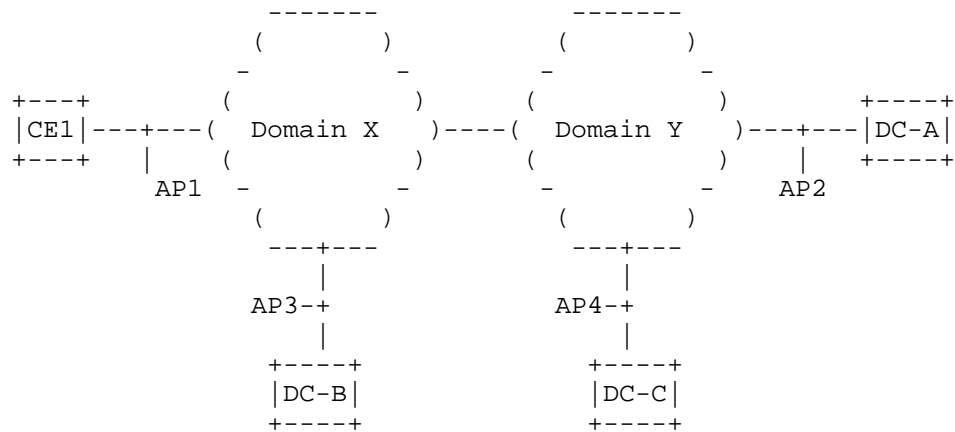


Figure 14: End-Point Selection Based on Network Status

7.1. Pre-Planned End Point Migration

Furthermore, in case of Data Center selection, customer could request for a backup DC to be selected, such that in case of failure, another DC site could provide hot stand-by protection. As shown in Figure 15 DC-C is selected as a backup for DC-A. Thus, the VN should be setup by the MDSC to include primary connectivity

between AP1 (CE1) and AP2 (DC-A) as well as protection connectivity between AP1 (CE1) and AP4 (DC-C).

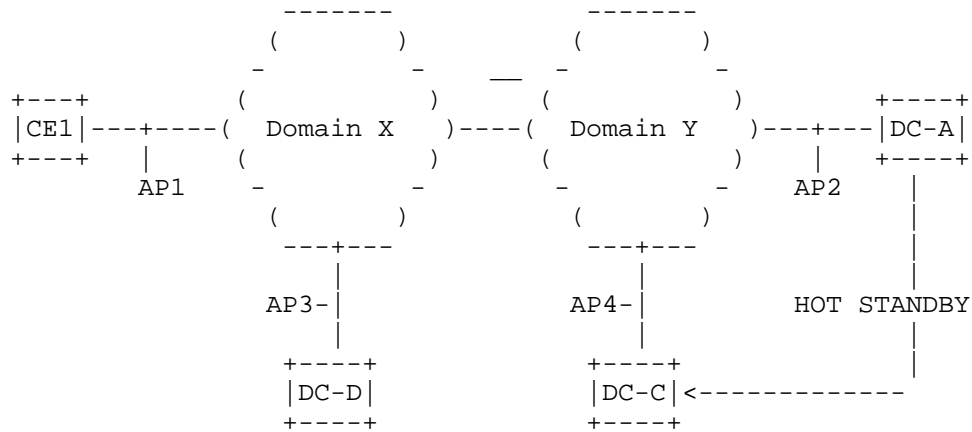


Figure 15: Pre-planned End-Point Migration

7.2. On the Fly End-Point Migration

Compared to pre-planned end point migration, on the fly end point selection is dynamic in that the migration is not pre-planned but decided based on network condition. Under this scenario, the MDSC would monitor the network (based on the VN Service-level Agreement (SLA) and notify the CNC in case where some other destination AP would be a better choice based on the network parameters. The CNC should instruct the MDSC when it is suitable to update the VN with the new AP if it is required.

8. Manageability Considerations

The objective of ACTN is to manage traffic engineered resources, and provide a set of mechanisms to allow customers to request virtual connectivity across server network resources. ACTN supports multiple customers each with its own view of and control of a virtual network built on the server network, the network operator will need to partition (or "slice") their network resources, and manage the resources accordingly.

The ACTN platform will, itself, need to support the request, response, and reservations of client and network layer connectivity. It will also need to provide performance monitoring and control of traffic engineered resources. The management requirements may be categorized as follows:

- . Management of external ACTN protocols
- . Management of internal ACTN interfaces/protocols
- . Management and monitoring of ACTN components
- . Configuration of policy to be applied across the ACTN system

The ACTN framework and interfaces are defined to enable traffic engineering for virtual network services and connectivity services. Network operators may have other Operations, Administration, and Maintenance (OAM) tasks for service fulfillment, optimization, and assurance beyond traffic engineering. The realization of OAM beyond abstraction and control of traffic engineered networks is not considered in this document.

8.1. Policy

Policy is an important aspect of ACTN control and management. Policies are used via the components and interfaces, during deployment of the service, to ensure that the service is compliant with agreed policy factors and variations (often described in SLAs), these include, but are not limited to: connectivity, bandwidth, geographical transit, technology selection, security, resilience, and economic cost.

Depending on the deployment of the ACTN architecture, some policies may have local or global significance. That is, certain policies may be ACTN component specific in scope, while others may have broader scope and interact with multiple ACTN components. Two examples are provided below:

- o A local policy might limit the number, type, size, and scheduling of virtual network services a customer may request via its CNC. This type of policy would be implemented locally on the MDSC.
- o A global policy might constrain certain customer types (or specific customer applications) to only use certain MDSCs, and be restricted to physical network types managed by the PNCs. A global policy agent would govern these types of policies.

The objective of this section is to discuss the applicability of ACTN policy: requirements, components, interfaces, and examples. This section provides an analysis and does not mandate a specific method for enforcing policy, or the type of policy agent that would

be responsible for propagating policies across the ACTN components. It does highlight examples of how policy may be applied in the context of ACTN, but it is expected further discussion in an applicability or solution specific document, will be required.

8.2. Policy Applied to the Customer Network Controller

A virtual network service for a customer application will be requested by the CNC. The request will reflect the application requirements and specific service needs, including bandwidth, traffic type and survivability. Furthermore, application access and type of virtual network service requested by the CNC, will be need adhere to specific access control policies.

8.3. Policy Applied to the Multi-Domain Service Coordinator

A key objective of the MDSC is to support the customer's expression of the application connectivity request via its CNC as a set of desired business needs, therefore policy will play an important role.

Once authorized, the virtual network service will be instantiated via the CNC-MDSC Interface (CMI); it will reflect the customer application and connectivity requirements, and specific service transport needs. The CNC and the MDSC components will have agreed connectivity end-points; use of these end-points should be defined as a policy expression when setting up or augmenting virtual network services. Ensuring that permissible end-points are defined for CNCs and applications will require the MDSC to maintain a registry of permissible connection points for CNCs and application types.

Conflicts may occur when virtual network service optimization criteria are in competition. For example, to meet objectives for service reachability a request may require an interconnection point between multiple physical networks; however, this might break a confidentiality policy requirement of specific type of end-to-end service. Thus an MDSC may have to balance a number of the constraints on a service request and between different requested services. It may also have to balance requested services with operational norms for the underlying physical networks. This balancing may be resolved using configured policy and using hard and soft policy constraints.

8.4. Policy Applied to the Provisioning Network Controller

The PNC is responsible for configuring the network elements, monitoring physical network resources, and exposing connectivity

(direct or abstracted) to the MDSC. It is therefore expected that policy will dictate what connectivity information will be exported between the PNC, via the MDSC-PNC Interface (MPI), and MDSC.

Policy interactions may arise when a PNC determines that it cannot compute a requested path from the MDSC, or notices that (per a locally configured policy) the network is low on resources (for example, the capacity on key links become exhausted). In either case, the PNC will be required to notify the MDSC, which may (again per policy) act to construct a virtual network service across another physical network topology.

Furthermore, additional forms of policy-based resource management will be required to provide virtual network service performance, security and resilience guarantees. This will likely be implemented via a local policy agent and additional protocol methods.

9. Security Considerations

The ACTN framework described in this document defines key components and interfaces for managed traffic engineered networks. Securing the request and control of resources, confidentiality of the information, and availability of function, should all be critical security considerations when deploying and operating ACTN platforms.

Several distributed ACTN functional components are required, and implementations should consider encrypting data that flows between components, especially when they are implemented at remote nodes, regardless these data flows are on external or internal network interfaces.

The ACTN security discussion is further split into two specific categories described in the following sub-sections:

- o Interface between the Customer Network Controller and Multi-Domain Service Coordinator (MDSC), CNC-MDSC Interface (CMI)
- o Interface between the Multi-Domain Service Coordinator and Provisioning Network Controller (PNC), MDSC-PNC Interface (MPI)

From a security and reliability perspective, ACTN may encounter many risks such as malicious attack and rogue elements attempting to connect to various ACTN components. Furthermore, some ACTN components represent a single point of failure and threat vector, and must also manage policy conflicts, and eavesdropping of communication between different ACTN components.

The conclusion is that all protocols used to realize the ACTN framework should have rich security features, and customer, application and network data should be stored in encrypted data stores. Additional security risks may still exist. Therefore, discussion and applicability of specific security functions and protocols will be better described in documents that are use case and environment specific.

9.1. CNC-MDSC Interface (CMI)

Data stored by the MDSC will reveal details of the virtual network services, and which CNC and customer/application is consuming the resource. The data stored must therefore be considered as a candidate for encryption.

CNC Access rights to an MDSC must be managed. The MDSC must allocate resources properly, and methods to prevent policy conflicts, resource wastage, and denial of service attacks on the MDSC by rogue CNCs, should also be considered.

The CMI will likely be an external protocol interface. Suitable authentication and authorization of each CNC connecting to the MDSC will be required, especially, as these are likely to be implemented by different organizations and on separate functional nodes. Use of the AAA-based mechanisms would also provide role-based authorization methods, so that only authorized CNC's may access the different functions of the MDSC.

9.2. MDSC-PNC Interface (MPI)

Where the MDSC must interact with multiple (distributed) PNCs, a PKI-based mechanism is suggested, such as building a TLS or HTTPS connection between the MDSC and PNCs, to ensure trust between the physical network layer control components and the MDSC. Trust anchors for the PKI can be configured to use a smaller (and potentially non-intersecting) set of trusted Certificate Authorities (CAs) than in the Web PKI.

Which MDSC the PNC exports topology information to, and the level of detail (full or abstracted), should also be authenticated, and specific access restrictions and topology views should be configurable and/or policy-based.

10. IANA Considerations

This document has no actions for IANA.

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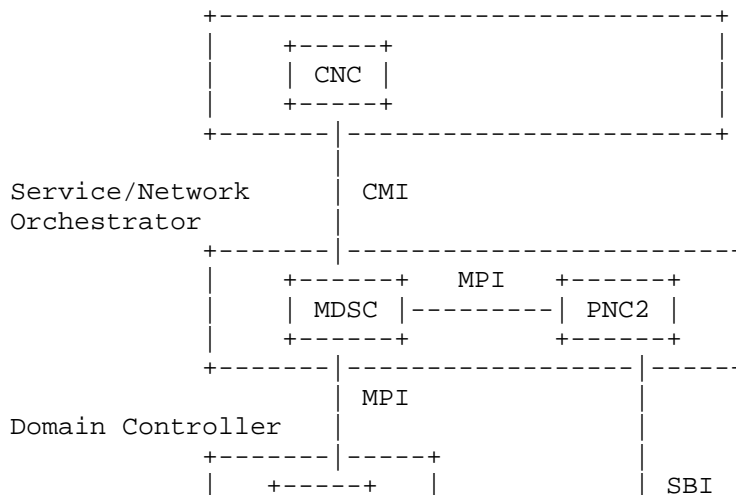
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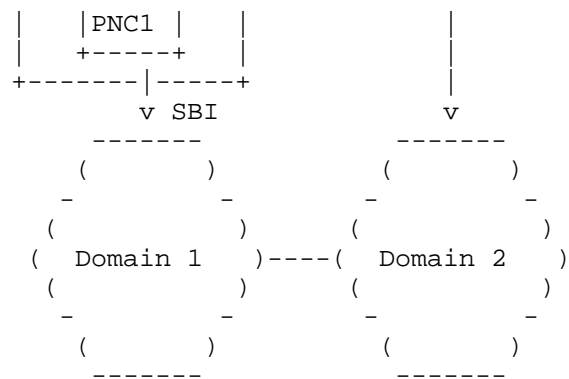
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APPENDIX A - Example of MDSC and PNC Functions Integrated in A Service/Network Orchestrator

This section provides an example of a possible deployment scenario, in which Service/Network Orchestrator can include a number of functionalities, among which, in the example below, PNC functionalities for domain 2 and MDSC functionalities to coordinate the PNC1 functionalities (hosted in a separate domain controller) and PNC2 functionalities (co-hosted in the network orchestrator).

Customer





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Information Model for Abstraction and Control of TE Networks (ACTN)

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Abstract

This draft provides an information model for Abstraction and Control of Traffic Engineered Networks (ACTN).

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1. Introduction

This draft provides an information model for Abstraction and Control of Traffic Engineered Networks (ACTN). The information model described in this document covers the interface requirements identified in the ACTN architecture and framework document [ACTN-Frame].

The ACTN reference architecture [ACTN-Frame] identifies a three-tier control hierarchy comprising the following as depicted in Figure 1:

- Customer Network Controllers (CNCs)
- Multi-Domain Service Coordinator (MDSC)
- Provisioning Network Controllers (PNCs).

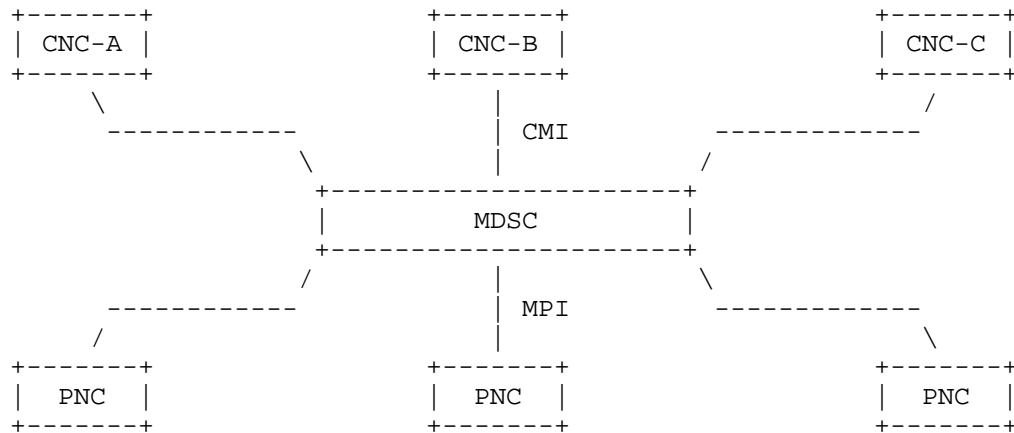


Figure 1: A Three-tier ACTN control hierarchy

The two interfaces with respect to the MDSC, one north of the MDSC and the other south of the MDSC are referred to as CMI (CNC-MDSC Interface) and MPI (MDSC-PNC Interface), respectively. This document models these two interfaces and derivative interfaces thereof (e.g., MDSC to MDSC in a hierarchy of MDSCs) as a single common interface.

1.1. Terminology

The terms "Virtual Network (VN)" and "Virtual Network Service (VNS)" are defined in [ACTN-Frame] and the other key terms such as "abstraction", "abstract topology", "Path", "VN node", and "VN link" are defined in [RFC7926].

2. ACTN Common Interfaces Information Model

This section provides an ACTN common interface information model to describe primitives, objects, their properties (represented as attributes), their relationships, and the resources for the service applications needed in the ACTN context.

The standard interface is described between a client controller and a server controller. A client-server relationship is recursive between a CNC and an MDSC and between an MDSC and a PNC. In the CMI,

the client is a CNC while the server is an MDSC. In the MPI, the client is an MDSC and the server is a PNC. There may also be MDSC-MDSC interface(s) that need to be supported. This may arise in a hierarchy of MDSCs in which workloads may need to be partitioned to multiple MDSCs.

Basic primitives (messages) are required between the CNC-MDSC and MDSC-PNC controllers. These primitives can then be used to support different ACTN network control functions like network topology request/query, VN service request, path computation and connection control, VN service policy negotiation, enforcement, routing options, etc.

There are two different types of primitives depending on the type of interface:

- Virtual Network primitives at CMI
- Traffic Engineering primitives at MPI

As well described in [ACTN-Frame], at the CMI level, there is no need for detailed TE information since the basic functionality is to translate customer service information into virtual network service operation.

At the MPI level, MDSC has the main scope for multi-domain coordination and creation of a single e2e abstracted network view which is strictly related to TE information.

As for topology, this document employs two types of topology:

- The first type is referred to as virtual network topology which is associated with a VN. Virtual network topology is a customized topology for view and control by the customer. See Section 3.1 for details.
- The second type is referred to as TE topology which is associated with provider network operation on which we can apply policy to obtain the required level of abstraction to represent the underlying physical network topology.

3. Virtual Network primitives

This section provides a list of main VN primitives related to virtual network which are necessary to satisfy ACTN requirements specified in [ACTN-REQ]

The following VN Action primitives are supported:

- VN Instantiate
- VN Modify
- VN Delete
- VN Update
- VN Path Compute
- VN Query

VN Action is an object describing the main VN primitives.

VN Action can assume one of the mentioned above primitives values.

```
<VN Action> ::= <VN Instantiate> |  
                <VN Modify> |  
                <VN Delete> |  
                <VN Update> |  
                <VN Path Compute> |  
                <VN Query>
```

All these actions will solely happen at CMI level between Customer Network Controller (CNC) and Multi Domain Service Coordinator (MDSC).

3.1. VN Instantiate

VN Instantiate refers to an action from customers/applications to request the creation of VNs. VN Instantiate is for CNC-to-MDSC communication. Depending on the agreement between client and provider, VN instantiate can imply different VN operations. There are two types of VN instantiation:

VN type 1: VN is viewed as a set of edge-to-edge links (VN members).

VN type 2: VN is viewed as a VN-topology comprising virtual nodes and virtual links.

Please see [ACTN-Frame] for full details regarding the types of VN.

3.2. VN Modify

VN Modify refers to an action issued from customers/applications to modify an existing VN (i.e., an instantiated VN). VN Modify is for CNC-to-MDSC communication.

VN Modify, depending of the type of VN instantiated, can be a modification of the characteristics of VN members (edge-to-edge links) in case of VN type 1, or a modification of an existing virtual topology (e.g., adding/deleting virtual nodes/links) in case of VN type 2.

3.3. VN Delete

VN Delete refers to an action issued from customers/applications to delete an existing VN. VN Delete is for CNC-to-MDSC communication.

3.4. VN Update

VN Update refers to any update to the VN that needs to be updated to the customers. VN Update is MDSC-to-CNC communication. VN Update fulfills a push model at CMI level, to make customers aware of any specific changes in the topology details related to the instantiated VN.

VN Update, depending of the type of VN instantiated, can be an update of VN members (edge-to-edge links) in case of VN type 1, or an update of virtual topology in case of VN type 2.

The connection-related information (e.g., LSPs) update association with VNs will be part of the "translation" function that happens in MDSC to map/translate VN request into TE semantics. This information will be provided in case customer optionally wants to have more detailed TE information associated with the instantiated VN.

3.5. VN Compute

VN Compute consists of Request and Reply. Request refers to an action from customers/applications to request a VN computation.

VN Compute Reply refers to the reply in response to VN Compute Request.

VN Compute Request/Reply is to be differentiated from a VN Instantiate. The purpose of VN Compute is a priori exploration to compute network resources availability and getting a possible VN view in which path details can be specified matching customer/applications constraints. This a priori exploration may not guarantee the availability of the computed network resources at the time of instantiation.

3.6. VN Query

VN Query refers to an inquiry pertaining to a VN that has already been instantiated. VN Query fulfills a pull model that permits getting a topology view.

VN Query Reply refers to the reply in response to VN Query. The topology view returned by VN Query Reply would be consistent with the topology type instantiated for any specific VN.

4. Traffic Engineering (TE) primitives

This section provides a list of the main TE primitives necessary to satisfy ACTN requirements specified in [ACTN-REQ] related to typical TE operations supported at the MPI level.

The TE action primitives defined in this section should be supported at the MPI consistently with the type of topology defined at the CMI.

The following TE action primitives are supported:

- TE Instantiate/Modify/Delete
- TE Topology Update (See Section 4.4. for the description)
- Path Compute

TE Action is an object describing the main TE primitives.

TE Action can assume one of the mentioned above primitives values.

```
<TE Action> ::= <TE Instantiate> |  
                <TE Modify> |  
                <TE Delete> |  
                <TE Topology Update> |
```

<Path Compute> |

All these actions will solely happen at MPI level between Multi Domain Service Coordinator (MDSC) and Provisioning Network Controller (PNC).

4.1. TE Instantiate

TE Instantiate refers to an action issued from MDSC to PNC to instantiate new TE tunnels.

4.2. TE Modify

TE Modify refers to an action issued from MDSC to PNC to modify existing TE tunnels.

4.3. TE Delete

TE Delete refers to an action issued from MDSC to PNC to delete existing TE tunnels.

4.4. TE Topology Update (for TE resources)

TE Topology Update is a primitive specifically related to MPI to provide TE resource update between any domain controller towards MDSC regarding the entire content of any "domain controller" actual TE topology or an abstracted filtered view of TE topology depending on negotiated policy.

See [TE-TOPO] for detailed YANG implementation of TE topology update.

<TE Topology Update> ::= <TE-topology-list>

<TE-topology-list> ::= <TE-topology> [<TE-topology-list>]

<TE-topology> ::= [<Abstraction>] <TE-Topology-identifier> <Node-list> <Link-list>

<Node-list> ::= <Node>[<Node-list>]

<Node> ::= <Node> <TE Termination Point-list>

<TE Termination Point-list> ::= <TE Termination Point> [<TE-Termination Point-list>]

<Link-list> ::= <Link>[<Link-list>]

Where

Abstraction provides information on level of abstraction (as determined a priori).

TE-topology-identifier is an identifier that identifies a specific te-topology, e.g., te-types:te-topology-id [TE-TOPO].

Node-list is detailed information related to a specific node belonging to a te-topology, e.g., te-node-attributes [TE-TOPO].

Link-list is information related to the specific link related belonging to a te-topology, e.g., te-link-attributes [TE-TOPO].

TE Termination Point-list is detailed information associated with the termination points of te-link related to a specific node, e.g., interface-switching-capability [TE-TOPO].

4.5. Path Compute

Path Compute consists of Request and Reply. Request refers to an action from MDSC to PNC to request a path computation.

Path Compute Reply refers to the reply in response to Path Compute Request.

The context of Path Compute is described in [Path-Compute].

5. VN Objects

This section provides a list of objects associated to VN action primitives.

5.1. VN Identifier

VN Identifier is a unique identifier of the VN.

5.2. VN Service Characteristics

VN Service Characteristics describes the customer/application requirements against the VNs to be instantiated.

```
<VN Service Characteristics> ::= <VN Connectivity Type>  
                                <VN Directionality>  
                                (<VN Traffic Matrix>...)  
                                <VN Survivability>
```

Where

```
<VN Connectivity Type> ::= <P2P> | <P2MP> | <MP2MP> | <MP2P> | <Multi-  
destination>
```

The Connectivity Type identifies the type of required VN Service. In addition to the classical type of services (e.g. P2P/P2MP etc.), ACTN defines the "multi-destination" service that is a new P2P service where the end points are not fixed. They can be chosen among a list of pre-configured end points or dynamically provided by the CNC.

VN Directionality indicates if a VN is unidirectional or bidirectional. This implies that each VN member that belongs to the VN has the same directionality as the VN.

```
<VN Traffic Matrix> ::= <Bandwidth>  
                        [<VN Constraints>]
```

The VN Traffic Matrix represents the traffic matrix parameters for the required service connectivity. Bandwidth is a mandatory parameter and a number of optional constraints can be specified in the VN Constraints (e.g. diversity, cost). They can include objective functions and TE metrics bounds as specified in [RFC5541].

Further details on the VN constraints are specified below:

```
<VN Constraints> ::= [<Layer Protocol>]
```

[<Diversity>]

(<Metric> | <VN Objective Function>)

Where:

Layer Protocol identifies the layer topology at which the VN service is requested. It could be for example MPLS, ODU, and OCh.

Diversity allows asking for diversity constraints for a VN Instantiate/Modify or a VN Path Compute. For example, a new VN or a path is requested in total diversity from an existing one (e.g. diversity exclusion).

<Diversity> ::= (<VN-exclusion> (<VN-id>...)) |
(<VN-Member-exclusion> (<VN-Member-id>...))

Metric can include all the Metrics (cost, delay, delay variation, latency), bandwidth utilization parameters defined and referenced by [RFC3630] and [RFC7471].

As for VN Objective Function See Section 5.4.

VN Survivability describes all attributes related to the VN recovery level and its survivability policy enforced by the customers/applications.

<VN Survivability> ::= <VN Recovery Level>

[<VN Tunnel Recovery Level>]

[<VN Survivability Policy>]

Where:

VN Recovery Level is a value representing the requested level of resiliency required against the VN. The following values are defined:

- . Unprotected VN
- . VN with per tunnel recovery: The recovery level is defined against the tunnels composing the VN and it is specified in the VN Tunnel Recovery Level.

<VN Tunnel Recovery Level> ::= <0:1> | <1+1> | <1:1> | <1:N> | <M:N> |

<On the fly restoration>

The VN Tunnel Recovery Level indicates the type of protection or restoration mechanism applied to the VN. It augments the recovery types defined in [RFC4427].

```
<VN Survivability Policy> ::= [<Local Reroute Allowed>]
                                [<Domain Preference>]
                                [<Push Allowed>]
                                [<Incremental Update>]
```

Where:

Local Reroute Allowed is a delegation policy to the Server to allow or not a local reroute fix upon a failure of the primary LSP.

Domain Preference is only applied on the MPI where the MDSC (client) provides a domain preference to each PNC (server), e.g., when an inter-domain link fails, then PNC can choose the alternative peering with this info.

Push Allowed is a policy that allows a server to trigger an updated VN topology upon failure without an explicit request from the client. Push action can be set as default unless otherwise specified.

Incremental Update is another policy that triggers an incremental update from the server since the last period of update. Incremental update can be set as default unless otherwise specified.

5.3. VN End-Point

VN End-Point Object describes the VN's customer end-point characteristics.

```
<VN End-Point> ::= (<Access Point Identifier>
                    [<Access Link Capability>]
```

[<Source Indicator>)]...

Where:

Access Point Identifier represents a unique identifier of the client end-point. They are used by the customer to ask for the setup of a virtual network instantiation. A VN End-Point is defined against each AP in the network and is shared between customer and provider. Both the customer and the provider will map it against their own physical resources.

Access Link Capability identifies the capabilities of the access link related to the given access point. (e.g., max-bandwidth, bandwidth availability, etc.)

Source Indicator indicates if an end-point is source or not.

5.4. VN Objective Function

The VN Objective Function applies to each VN member (i.e., each E2E tunnel) of a VN.

The VN Objective Function can reuse objective functions defined in [RFC5541] section 4.

For a single path computation, the following objective functions are defined:

- o MCP is the Minimum Cost Path with respect to a specific metric (e.g. shortest path).
- o MLP is the Minimum Load Path, that means find a path composted by te-link least loaded.
- o MBP is the Maximum residual Bandwidth Path.

For a concurrent path computation, the following objective functions are defined:

- o MBC is to Minimize aggregate Bandwidth Consumption.
- o MLL is to Minimize the Load of the most loaded Link.
- o MCC is to Minimize the Cumulative Cost of a set of paths.

5.5. VN Action Status

VN Action Status is the status indicator whether the VN has been successfully instantiated, modified, or deleted in the server network or not in response to a particular VN action.

Note that this action status object can be implicitly indicated and thus not included in any of the VN primitives discussed in Section 3.

5.6. VN Topology

When a VN is seen by the customer as a topology, it is referred to as VN topology. This is associated with VN Type 2, which is composed of virtual nodes and virtual links.

<VN Topology> ::= <VN node list> <VN link list>

<VN node list> ::= <VN node> [<VN node list>]

<VN link list> ::= <VN link> [<VN link list>]

5.7. VN Member

VN Member describes details of a VN Member which is a list of a set of VN Members represented as VN_Member_List.

<VN_Member_List> ::= <VN Member> [<VN_Member_List>]

Where <VN Member> ::= <Ingress VN End-Point>

[<VN Associated LSP>]

<Egress VN End-Point>

Ingress VN End-Point is the VN End-Point information for the ingress portion of the AP. See Section 5.3 for VN End-Point details.

Egress VN End-Point is the VN End-Point information for the egress portion of the AP. See Section 5.3 for VN End-Point details.

VN Associated LSP describes the instantiated LSPs in the Provider's network for the VN Type 1. It describes the instantiated LSPs over the VN topology for VN Type 2.

5.7.1. VN Computed Path

The VN Computed Path is the list of paths obtained after the VN path computation request from a higher controller. Note that the computed path is to be distinguished from the LSP. When the computed path is signaled in the network (and thus the resource is reserved for that path), it becomes an LSP.

<VN Computed Path> ::= (<Path>...)

5.7.2. VN Service Preference

This section provides VN Service preference. VN Service is defined in Section 2.

<VN Service Preference> ::= [<Location Service Preference >]
[<Client-specific Preference >]
[<End-Point Dynamic Selection Preference >]

Where

Location Service Preference describes the End-Point Location's (e.g. Data Centers) support for certain Virtual Network Functions (VNFs) (e.g., security function, firewall capability, etc.) and is used to find the path that satisfies the VNF constraint.

Client-specific Preference describes any preference related to Virtual Network Service (VNS) that application/client can enforce via CNC towards lower level controllers. For example, CNC can enforce client-specific preferences, e.g., selection of a destination data center from the set of candidate data centers based on some criteria in the context of VM migration. MSDC/PNC should then provide the data center interconnection that supports the client-specific preference.

End-Point Dynamic Selection Preference describes if the End-Point (e.g. Data Center) can support load balancing, disaster recovery or VM migration and so can be part of the selection by MDSC following service Preference enforcement by CNC.

6. TE Objects

6.1. TE Tunnel Characteristics

Tunnel Characteristics describes the parameters needed to configure TE tunnel.

```
<TE Tunnel Characteristics> ::= [<Tunnel Type>]
                                <Tunnel Id>
                                [<Tunnel Layer>]
                                [<Tunnel end-point>]
                                [<Tunnel protection-restoration>]
                                <Tunnel Constraints>
                                [<Tunnel Optimization>]
```

Where

```
<Tunnel Type> ::= <P2P>|<P2MP>|<MP2MP>|<MP2P>
```

The Tunnel Type identifies the type of required tunnel. In this draft, only P2P model is provided.

Tunnel Id is the TE tunnel identifier

Tunnel Layer represents the layer technology of the LSPs supporting the tunnel

```
<Tunnel End Points> ::= <Source> <Destination>
```

```
<Tunnel protection-restoration> ::= <prot 0:1>|<prot 1+1>|<prot 1:1>|<prot 1:N>|<prot <M:N>|<restoration>
```

Tunnel Constraints are the base tunnel configuration constraints parameters.

```
Where <Tunnel Constraints> ::= [<Topology Id>]
                                [<Bandwidth>]
                                [<Disjointness>]
                                [<SRLG>]
                                [<Priority>]
                                [<Affinities>]
                                [<Tunnel Optimization>]
                                [<Objective Function>]
```

Topology Id references the topology used to compute the tunnel path.

Bandwidth is the bandwidth used as parameter in path computation

```
<Disjointness> ::= <node> | <link> | <srlg>
```

Disjointness provides the type of resources from which the tunnel has to be disjointed

SRLG is a group of physical resources impacted by the same risk from which an E2E tunnel is required to be disjointed.

```
<Priority> ::= <Holding Priority> <Setup Priority>
```

where

Setup Priority indicates the level of priority for taking resources from another tunnel [RFC3209]

Holding Priority indicates the level of priority to hold resources avoiding preemption from another tunnel [RFC3209]

Affinities it represent structure to validate link belonging to path of the tunnel [RFC3209]

```
<Tunnel Optimization> ::= <Metric> | <Objective Function>
```

Metric can include all the Metrics (cost, delay, delay variation, latency), bandwidth utilization parameters defined and referenced by [RFC3630] and [RFC7471].

<Objective Function> ::= <objective function type>

<objective function type> ::= <MCP> | <MLP> | <MBP> | <MBC> | <MLL>
| <MCC>

See chapter 5.4 for objective function type description.

7. Mapping of VN primitives with VN Objects

This section describes the mapping of VN primitives with VN Objects based on Section 5.

<VN Instantiate> ::= <VN Service Characteristics>

<VN Member-List>

[<VN Service Preference>]

[<VN Topology>]

<VN Modify> ::= <VN identifier>

<VN Service Characteristics>

<VN Member-List>

[<VN Service Preference>]

[<VN Topology>]

<VN Delete> ::= <VN Identifier>

<VN Update> :: = <VN Identifier>

[<VN Member-List>]

[<VN Topology>]

<VN Path Compute Request> ::= <VN Service Characteristics>

<VN Member-List>

[<VN Service Preference>]

<VN Path Compute Reply> ::= <VN Computed Path>

<VN Query> ::= <VN Identifier>

<VN Query Reply> ::= <VN Identifier>

<VN Associated LSP>

[<TE Topology Reference>]

8. Mapping of TE primitives with TE Objects

This section describes the mapping of TE primitives with TE Objects based on Section 6.

<TE Instantiate> ::= <TE Tunnel Characteristics>

<TE Modify> ::= <TE Tunnel Characteristics>

<TE Delete> ::= <Tunnel Id>

<TE Topology Update> ::= <TE-topology-list>

<Path Compute Request> ::= <TE Tunnel Characteristics>

<Path Compute Reply> ::= <TE Computed Path>

<TE Tunnel Characteristics>

9. Security Considerations

The ACTN information model is not directly relevant when considering potential security issues. Rather, it defines a set of interfaces for traffic engineered networks. The underlying protocols, procedures, and implementations used to exchange the information model described in this draft will need to secure the request and control of resources with proper authentication and authorization mechanisms. In addition, the data exchanged over the ACTN interfaces discussed in this document requires verification of data integrity. Backup or redundancies should also be available to restore the affected data to its correct state.

Implementations of the ACTN framework will have distributed functional components that will exchange a concrete instantiation that adheres to this information model. Implementations should encrypt data that flows between them, especially when they are implemented at remote nodes and irrespective of whether these data flows are on external or internal network interfaces. The information model may contain customer, application and network data that for business or privacy reasons may be considered sensitive. It should be stored only in an encrypted data store.

The ACTN security discussion is further split into two specific interfaces:

- Interface between the Customer Network Controller and Multi Domain Service Coordinator (MDSC), CNC-MDSC Interface (CMI)
- Interface between the Multi Domain Service Coordinator and Provisioning Network Controller (PNC), MDSC-PNC Interface (MPI)

See the detailed discussion of the CMI and MPI in Sections 9.1 and 9.2, respectively in [ACTN-Frame].

The conclusion is that all data models and protocols used to realize the ACTN info model should have rich security features as discussed in this section. Additional security risks may still exist. Therefore, discussion and applicability of specific security functions and protocols will be better described in documents that are use case and environment specific.

10. IANA Considerations

This document has no actions for IANA.

11. References

11.1. Normative References

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Requirements for Abstraction and Control of TE Networks

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Abstract

This document provides a set of functional requirements for abstraction and control of Traffic Engineering networks to facilitate virtual network operation via the creation of a single virtualized network or a seamless service. This supports operators in viewing and controlling different domains (at any dimension: applied technology, administrative zones, or vendor-specific technology islands) as a single virtualized network.

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1. Introduction

This document provides a set of functional requirements for Abstraction and Control of Traffic Engineering (TE) Networks (ACTN) identified in various use-cases specified by the operators. [ACTN-Frame] defines the base reference architecture and terminology.

ACTN refers to the set of virtual network service operations needed to coordinate, control and manage large-scale multi-domain TE networks so as to facilitate network programmability, automation, efficient resource sharing, and end-to-end virtual service aware connectivity.

These operations are summarized as follows:

- Abstraction and coordination of underlying network resources independent of how these resources are managed or controlled, so that higher-layer entities can dynamically control virtual networks based on those resources. Control includes creating, modifying, monitoring, and deleting virtual networks.
- Collation of the identifiers and other attributes of the resources from multiple TE networks (multiple technologies, equipment from multiple vendors, under the control of multiple administrations) through a process of recursive abstraction to present a customer with a single virtual network. This is achieved by presenting the network domain as an abstracted topology to the customer via open and programmable interfaces. Recursive abstraction allows for the recursion of abstracted data in a hierarchy of controllers.. It is expected that the recursion levels should be at least three levels: customer level, multi-domain network level, and domain network level.
- Coordination of end-to-end virtual network services and applications via allocation of network resources to meet specific service, application and customer requirements. Refer to [ACTN-Frame] for the definition of coordination.
- Adaptation of customer requests (to control virtual resources) to the physical network resources performing the necessary mapping, translation, isolation and, policy that allows conveying, managing and enforcing customer policies with respect to the services and the network of the customer.

- Provision via a data model and virtual control capability to customers who request virtual network services. Note that these customers could, themselves, be service providers.

ACTN solutions will build on, and extend, existing TE constructs and TE mechanisms wherever possible and appropriate. Support for controller-based approaches is specifically included in the possible solution set.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. High-level ACTN requirements

This section provides a summary of use-cases in terms of two categories: (i) service-specific requirements; (ii) network-related requirements. All these requirements are specified by operators that are interested in implementing ACTN.

Service-specific requirements listed below are uniquely applied to the work scope of ACTN. Service-specific requirements are related to the virtual service coordination function. These requirements are related to customer's Virtual Networks (VN) in terms of service policy associated with VNs such as service performance objectives, VN endpoint location information for certain required service specific functions (e.g., security and others), VN survivability requirement, or dynamic service control policy, etc.

Network-related requirements are related to and necessary for coherent/seamless for the virtual network operation function. These requirements are related to multi-domain and multi-layer signaling, routing, protection/restoration and re-optimization/re-grooming, etc.

Each requirement specified in Sections 2.1 and 2.2 is derived from ACTN use-cases: [CHENG], [DHODY], [FANG], [KLEE], [KUMAKI], [LOPEZ], [SHIN], [XU], [XU2], and [SUZUKI].

2.1. Service-Specific Requirements

1. Requirement 1: Virtual Network Service (VNS) creation

Customer MUST be able to request/instantiate the VNS to the network within the confines of mutual agreement between customer and network operator and network operator's capability. A VNS is the service agreement between a customer and provider to provide a VN [ACTN-Frame]. There are different types of VNS in terms of the VN types the customer is allowed to operate (e.g., a VN type can be simply a set of edge-to-edge links, or it can comprise of virtual nodes and virtual links, etc.). The customer MUST be able to express VNS preference that captures Service Level Agreements (SLA) associated with virtual network service (e.g., Endpoint selection preference, routing preference, time-related preference, etc.)

Reference: [KLEE], [LOPEZ], [SHIN], [DHODY], [FANG].

2. Requirement 2: Virtual Network Service Query

Customer SHOULD be able to request VNS Query ("Can you give me these VN(s)?") that include the following parameters:

- VN type: various VN types defined by the customer (e.g., path, graph, etc.)
- VN end-points (Customer Edge interface information)
- VN Topology Service-specific Objective Functions (e.g., a set of objective functions as defined in [RFC5541] to be supported on the paths, but not limited to).
- VN constraints requirement (e.g., Maximum Latency threshold, Minimum Bandwidth, etc.)

Reference: [KUMAKI], [FANG], [CHENG].

3. Requirement 3: VNS Instantiation ("Please create a VNS for me")

Customer MUST be able to instantiate VNS that includes various VNS related parameters:

- VN type: various VN types defined by the customer (e.g., Type 1, Type 2, etc. See [ACTN-Frame] for the definition of VN Type 1 and Type 2).
- VN end-points (Customer Edge interface information)
- VN Topology Service-specific Objective Functions (e.g., a set of objective functions as defined in [RFC5541] to be supported on the paths, but not limited to).
- VN constraints requirement (e.g., Maximum Latency threshold, Minimum Bandwidth, etc.)
- VN Topology diversity when there are multiple instances of VNS (e.g., VN1 and VN2 must be disjoint; Node/link disjoint from other VNs)

Note that Requirement 3 provides specific details of Requirement 1.

Reference: [KUMAKI], [FANG], [CHENG].

4. Requirement 4: VNS Lifecycle Management & Operation (M&O)

Customer MUST be able to perform the following VNS operations:

- VNS Delete: Customer MUST be able to delete VNS.
- VNS Modify: Customer MUST be able to modify VNS related parameters during the lifecycle of the instantiated VNS.

Reference: [FANG], [KUMAKI], [LOPEZ], [DHODY], [FANG], [KLEE].

5. Requirement 5: VNS Isolation

Customer's VN should be able to use arbitrary network topology, routing, or forwarding functions as well as customized control mechanisms independent of the underlying physical network and of other coexisting virtual networks. Other customers' VNS operation MUST NOT impact a particular customer's VNS network operation.

Reference: [KUMAKI], [FANG], [LOPEZ]

6. Requirement 6: Multi-Destination Coordination

Customer MUST be able to define and convey service/preference requirements for multi-destination applications (e.g., set of candidate sources/destinations, thresholds for load balancing, disaster recovery preference, etc.)

Reference: [FANG], [LOPEZ], [SHIN].

7. Requirement 7: VNS Performance Monitoring

The customer MUST be able to define performance monitoring parameters and its associated preference such as frequency of report, abstraction/aggregation level of performance data (e.g., VN level, tunnel level, etc.) with dynamic feedback loop from the network.

Reference: [XU], [XU2], [DHODY], [CHENG]

8. Requirement 8: VNS Confidentiality and Security Requirements

The following confidentiality/security requirements MUST be supported in all interfaces:

- Securing the request and control of resources, confidentiality of the information, and availability of function.
- Trust domain verification between a customer entity and a network entity. It verifies if a trust relationship has been established between these entities.
- Encrypting data that flow between components, especially when they are implemented at remote nodes, regardless if these are external or internal network interfaces.

Reference: [KUMAKI], [FANG], [LOPEZ]

2.2. Network-Related Requirements

1. Requirement 1: Virtual Network Service Coordination

Network MUST be able to support the following VNS operations:

- VNS Create: Upon customer's VNS creation request, network MUST be able to create VNS within the confines of network resource availability.
- VNS Delete: Upon customer's VNS deletion request, network MUST be able to delete VNS.
- VNS Modify: Upon customer's VNS modification request, network MUST be able to modify VNS related parameters during the lifecycle of the instantiated VNS.
- VNS Monitor: Upon customer's VNS performance monitoring setup, the network MUST be able to support VNS level Operations, Administration and Management (OAM) Monitoring under service agreement.

Reference: [FANG], [KUMAKI], [LOPEZ], [DHODY], [FANG], [KLEE].

2. Requirement 2: Topology Abstraction Capability

The network MUST be capable of managing its networks based on the principle of topology abstraction to be able to scale multi-layer, multi-domain networks.

Reference: [KLEE], [LOPEZ], [DHODY], [CHENG].

3. Requirement 3: Multi-Domain & Multi-layer Coordination

Network coordination for multi-domain and multi-layer path computation and path setup operation MUST be provided:

- End-to-end path computation across multi-domain networks (based on abstract topology from each domain)
- Domain sequence determination
- Request for path signaling to each domain controller
- Alternative TE path computation if any of the domain controllers cannot find its domain path

Reference: [CHENG], [DHODY], [KLEE], [LOPEZ], [SHIN], [SUZUKI].

4. Requirement 4: End-to-End Path Protection

End-to-end Path Protection Operations MUST be provided with seamless coordination between domain-level protection schemes and cross-domain protection schemes.

Reference: [CHENG], [KLEE], [DHODY], [LOPEZ], [SHIN].

5. Requirement 5: Dynamicity of virtual network control operations

Dynamic virtual network control operations MUST be supported. This includes, but is not limited to, the following:

- Real-time VNS control (e.g., fast recovery/reroute upon network failure).
- Fast convergence of abstracted topologies upon changes due to failure or reconfiguration across the network domain view, the multi-domain network view and the customer view.
- Large-scale VNS operation (e.g., the ability to process tens of thousands of connectivity requests) for time-sensitive applications.

Reference: [SHIN], [XU], [XU2], [KLEE], [KUMAKI], [SUZUKI].

3. Security Considerations

The ACTN requirements described in this document do not directly bear specific security concerns. When these requirements are implemented in specific interfaces, securing the request and control of resources, confidentiality of the information, and availability of function, should all be critical security considerations.

4. IANA Considerations

This document has no actions for IANA.

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Recommendations for RSVP-TE and Segment Routing LSP co-existence
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Abstract

Operators are looking to introduce services over Segment Routing (SR) LSPs in networks running Resource Reservation Protocol (RSVP-TE) LSPs. In some instances, operators are also migrating existing services from RSVP-TE to SR LSPs. For example, there might be certain services that are well suited for SR and need to co-exist with RSVP-TE in the same network. Such introduction or migration of traffic to SR might require co-existence with RSVP-TE in the same network for an extended period of time depending on the operator's intent. The following document provides solution options for keeping the traffic engineering database consistent across the network, accounting for the different bandwidth utilization between SR and RSVP-TE.

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1. Introduction

Introduction of SR [I-D.ietf-spring-segment-routing] in the same network domain as RSVP-TE [RFC3209] presents the problem of accounting for SR traffic and making RSVP-TE aware of the actual available bandwidth on the network links. RSVP-TE is not aware of how much bandwidth is being consumed by SR services on the network links and hence both at computation time (for a distributed computation) and at signaling time RSVP-TE LSPs will incorrectly place loads. This is true where RSVP-TE paths are distributed or centrally computed without a common entity managing both SR and RSVP-TE computation for the entire network domain.

The problem space can be generalized as a dark bandwidth problem to cases where any other service exists in the network that runs in parallel across common links and whose bandwidth is not reflected in the available and reserved values in the traffic engineering database (TED). In most practical instances given the static nature of the traffic demands, limiting the available reservable bandwidth available to RSVP-TE has been an acceptable solution. However, in the case of SR traffic, there is assumed to be very dynamic traffic demands and there is considerable risk associated with stranding capacity or overbooking service traffic resulting in traffic drops.

The high level requirements to consider are:

1. Placement of SR LSPs in the same domain as RSVP-TE LSPs must not introduce inaccuracies in the TED used by distributed or centralized path computation engines.
2. Engines that compute RSVP-TE paths may have no knowledge of the existence of the SR paths in the same domain.
3. Engines that compute RSVP-TE paths should not require a software upgrade or change to their path computation logic.
4. Protocol extensions should be avoided or be minimal as in many cases this co-existence of RSVP-TE and SR may be needed only during a transition phase.
5. Placement of SR LSPs in the same domain as RSVP-TE LSPs that are computed in a distributed fashion must not require migration to a central controller architecture for the RSVP-TE LSPs.

2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

3. Solution options

The following section lists SR and RSVP co-existence solution options. A specific solution is not recommended as all solutions are valid even though some may not satisfy all the requirements. If a solution is acceptable for an operator based on their deployment model then such a solution can be chosen.

3.1. Static partitioning of bandwidth

In this model, the static reservable bandwidth of an interface can be statically partitioned between SR and RSVP-TE and each can operate within that bandwidth allocation and SHOULD NOT preempt each other.

While it is possible to configure RSVP-TE to only reserve up to a certain maximum link bandwidth and manage the remaining link bandwidth for other services, this is a deployment where SR and RSVP-TE are separated in the same network (ships in the night) and can lead to suboptimal link bandwidth utilization not allowing each to consume more, if required and constraining the respective deployments.

The downside of this approach is the inability to use the reservable bandwidth effectively and inability to use bandwidth left unused by the other protocol.

3.2. Centralized management of available capacity

In this model, a central controller performs path placement for both RSVP-TE and SR LSPs. The controller manages and updates its own view of the in-use and the available capacity. As the controller is a single common entity managing the network it can have a unified and consistent view of the available capacity at all times.

A practical drawback of this model is that it requires the introduction of a central controller managing the RSVP-TE LSPs as a prerequisite to the deployment of any SR LSPs. Therefore, this approach is not practical for networks where distributed TE with RSVP-TE LSPs is already deployed, as it requires a redesign of the network and is not backwards compatible. This does not satisfy requirement 5.

Note that it is not enough for the controller to just maintain the unified view of the available capacity, it must also perform the path computation for the RSVP-TE LSPs, as the reservations for the SR LSPs are not reflected in the TED.

3.3. Flooding SR utilization in IGP

Using techniques in [RFC7810], [RFC7471] and [RFC7823], the SR utilization information can be flooded in IGP-TE and the RSVP-TE path computation engine (CSPF) can be changed to consider this information. This requires changes to the RSVP-TE path computation logic and would require upgrades in deployments where distributed computation is done across the network.

This does not fit with requirements 3 and 4 mentioned earlier.

3.4. Running SR over RSVP-TE

SR can run over dedicated RSVP-TE LSPs that carry only SR traffic. In this model, the LSPs can be one-hop or multi-hop and can provide bandwidth reservation for the SR traffic based on functionality such as auto-bandwidth. The model of deployment would be similar in nature to running LDP over RSVP-TE. This would allow the TED to stay consistent across the network and any other RSVP-TE LSPs will also be aware of the SR traffic reservations. In this approach, non-SR traffic MUST NOT take the SR-dedicated RSVP-TE LSPs, unless required by policy.

The drawback of this solution is that it requires SR to rely on RSVP-TE for deployment. Furthermore, the accounting accuracy/frequency of this method is dependent on performance of auto-bandwidth for RSVP-TE. Note that for this method to work, the SR-dedicated RSVP-TE LSPs must be set up with the best setup and hold priorities in the network.

3.5. TED consistency by reflecting SR traffic

The solution relies on dynamically measuring SR traffic utilization on each TE interface and reducing the bandwidth allowed for use by RSVP-TE. It is assumed that SR traffic receives precedence in terms of the placement on the path over RSVP traffic (that is, RSVP traffic can be preempted from the path in case of insufficient resources). This is logically equivalent to SR traffic having the best preemption priority in the network. Note that this does not necessarily mean that SR traffic has higher QoS priority, in fact, SR and RSVP traffic may be in the same QoS class.

Reducing the bandwidth allowed for use by RSVP-TE can be explored using the three parameters available in IGP-TE ([RFC5305],[RFC3630]), namely Maximum-Link-Bandwidth, Maximum-Reservable-Bandwidth and Unreserved-Bandwidth.

- o Maximum-Link-Bandwidth: This parameter can be adjusted to accommodate the bandwidth required for SR traffic with cascading impacts on Maximum-Reservable-Bandwidth and Unreserved-Bandwidth. However, changing the maximum bandwidth for the TE link will prevent any compute engine for SR or RSVP from determining the real static bandwidth of the TE link. Further, when the Maximum-Reservable-Bandwidth is derived from the Maximum-Link-Bandwidth, its definition changes since Maximum-Link-Bandwidth will account for the SR traffic.

- o Unreserved-Bandwidth: SR traffic could directly adjust the Unreserved-Bandwidth, without impacting Maximum-Link-Bandwidth or Maximum-Reservable-Bandwidth. This model is equivalent to the option described in Section 3.4. Furthermore this would result in overloading IGP-TE advertisements to directly reflect both RSVP-TE bandwidth bookings and SR bandwidth measurements.
- o Maximum-Reservable-Bandwidth: As the preferred option, SR traffic could adjust the Maximum-Reservable-Bandwidth, with cascading impact on the Unreserved-Bandwidth.

The following methodology can be used at every TE node for this solution, using the following parameters:

- o T: Traffic statistics collection time interval
- o k: The number of traffic statistics samples that can provide a smoothing function to the statistics collection. The value of k is a constant integer multiplier greater or equal to 1.
- o N: Traffic averaging calculation (adjustment) interval such that $N = k * T$
- o Maximum-Reservable-Bandwidth: The maximum available bandwidth for RSVP-TE.

If Differentiated-Service (Diffserv)-aware MPLS Traffic Engineering (DS-TE) [RFC4124] is enabled, the Maximum-Reservable-Bandwidth SHOULD be interpreted as the aggregate bandwidth constraint across all Class-Types independent of the Bandwidth Constraints model.

- o Initial Maximum-Reservable-Bandwidth: The Maximum-reservable-bandwidth for TE when no SR traffic or RSVP-TE reservations exist on the interface.
- o RSVP-unreserved-bandwidth-at-priority-X: Maximum-Reservable-Bandwidth - sum of (existing reservations at priority X and all priorities better than X)
- o SR traffic threshold percentage: The percentage difference of traffic demand that when exceeded can result in a change to the RSVP-TE Maximum-Reservable-Bandwidth
- o IGP-TE update threshold: Specifies the frequency at which IGP-TE updates should be triggered based on TE bandwidth updates on a link

- o M: An optional multiplier that can be applied to the SR traffic average. This multiplier provides the ability to grow or shrink the bandwidth used by SR. Appendix A offers further guidance on M.

At every interval T, each node SHOULD collect the SR traffic statistics for each of its TE interfaces. The measured SR traffic includes all labelled SR traffic and any traffic entering the SR network over that TE interface. Further, at every interval N, given a configured SR traffic threshold percentage and a set of collected SR traffic statistics samples across the interval N, the SR traffic average (or any other traffic metric depending on the algorithm used) over this period is calculated. This method of sampling traffic statistics and adjusting bandwidth reservation accordingly is similar to how bandwidth gets adjusted for auto-bandwidth RSVP-TE LSPs.

If the difference between the new calculated SR traffic average and the current SR traffic average (that was computed in the prior adjustment) is at least SR traffic threshold percentage, then two values MUST be updated:

- o New Maximum-Reservable-Bandwidth = Initial Maximum-Reservable-Bandwidth - (new SR traffic average * M)
- o New RSVP-unreserved-bandwidth-at-priority-X = New Maximum-Reservable-Bandwidth - sum of (existing reservations at priority X and all priorities better than X)

A DS-TE LSR that advertises Bandwidth Constraints TLV should update the bandwidth constraints for class-types based on operator policy. For example, when Russian Dolls Model (RDM) [RFC4127] is in use, then only BC0 may be updated. Whereas, when Maximum Allocation Model (MAM) [RFC4125] is in use, then all BCs may be updated equally such that the total value updated is equal to the newly calculated SR traffic average.

Note that the computation of the new RSVP-unreserved-bandwidth-at-priority-X MAY result in RSVP-TE LSPs being hard or soft preempted. Such preemption will be based on relative priority (e.g. low to high) between RSVP-TE LSPs. The IGP-TE update threshold SHOULD allow for more frequent flooding of unreserved bandwidth. From an operational point of view, an implementation SHOULD be able to expose both the configured and the actual values of the Maximum-Reservable-Bandwidth.

If LSP preemption is not acceptable, then the RSVP-TE Maximum-Reservable-Bandwidth cannot be reduced below what is currently reserved by RSVP-TE on that interface. This may result in bandwidth not being available for SR traffic. Thus, it is required that any

external controller managing SR LSPs SHOULD be able to detect this situation (for example by subscribing to TED updates [RFC7752]) and SHOULD take action to reroute existing SR paths.

Generically, SR traffic (or any non-RSVP-TE traffic) should have its own priority allocated from the available priorities. This would allow SR to preempt other traffic according to the preemption priority order.

In this solution, the logic to retrieve the statistics, calculating averages and taking action to change the Maximum-Reservable-Bandwidth is an implementation choice, and all changes are local in nature. However, note that this is a new network trigger for RSVP-TE preemption and thus is a consideration for the operator.

The above solution offers the advantage of not introducing new network-wide mechanisms especially during scenarios of migrating to SR in an existing RSVP-TE network and reusing existing protocol mechanisms.

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6. IANA Considerations

This draft does not have any request for IANA.

7. Security Considerations

This document describes solution options for the co-existence of RSVP-TE and SR LSPs in the same administrative domain. The security considerations for SR are described in [I-D.ietf-spring-segment-routing]. The security considerations pertaining to RSVP-TE are described in [RFC5920]. The security considerations of each architecture are typically unaffected by the presence of the other. However, when RSVP-TE and SR LSPs co-exist, it is possible for a hijacked SR traffic stream to maliciously consume sufficient bandwidth and cause disruption to RSVP-TE LSPs. With the solution option specified in Section 3.5, the impact to RSVP-TE traffic can be controlled and paths re-routed. Some latent risk of disruption still remains because this solution option relies on taking statistics samples and adopting to new traffic flows only after the adjustment period. The defensive mechanisms described in the base SR security framework should be employed to guard against situations that result in SR traffic hijacking or denial of service.

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<<https://www.rfc-editor.org/info/rfc7823>>.

Appendix A. Multiplier value range

The following is a suggestion for the range of values for M:

M is a per-node positive real number that ranges from 0 to 2 with a default of 1 and may be expressed as a percentage.

- o If $M < 1$, then the SR traffic average is being understated, which can result in the link getting full even though Maximum-Reservable-Bandwidth does not reach zero.
- o If $M > 1$, then the SR traffic average is overstated, thereby resulting in the Maximum-Reservable-Bandwidth reaching zero before the link gets full. If the reduction of Maximum-Reservable-Bandwidth becomes a negative value, then a value of zero SHOULD be used and advertised.

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A YANG Data Model for RSVP-TE Protocol
draft-ietf-teas-yang-rsvp-te-09

Abstract

This document defines a YANG data model for the configuration and management of RSVP (Resource Reservation Protocol) to establish Traffic-Engineered (TE) Label-Switched Paths (LSPs) for MPLS (Multi-Protocol Label Switching) and other technologies.

The model defines a generic RSVP-TE module for signaling LSPs that are technology agnostic. The generic RSVP-TE module is to be augmented by technology specific RSVP-TE modules that define technology specific data. This document also defines the augmentation for RSVP-TE MPLS LSPs model.

This model covers data for the configuration, operational state, remote procedural calls, and event notifications.

Status of This Memo

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1. Introduction

YANG [RFC7950] is a data modeling language that was introduced to define the contents of a conceptual data store that allows networked devices to be managed using NETCONF [RFC6241]. YANG has proved relevant beyond its initial confines, as bindings to other interfaces (e.g. RESTCONF [RFC8040]) and encoding other than XML (e.g. JSON) are being defined. Furthermore, YANG data models can be used as the

basis of implementation for other interfaces, such as CLI and programmatic APIs.

This document defines a generic YANG data model for configuring and managing RSVP-TE LSP(s) [RFC3209]. The RSVP-TE generic model augments the RSVP base and extended models defined in [I-D.ietf-teas-yang-rsvp], and adds TE extensions to the RSVP protocol [RFC2205] model configuration and state data. The technology specific RSVP-TE models augment the generic RSVP-TE model with additional technology specific parameters. For example, this document also defines the MPLS RSVP-TE model for configuring and managing MPLS RSVP TE LSP(s).

In addition to augmenting the RSVP YANG module, the modules defined in this document augment the TE Interfaces, Tunnels and LSP(s) YANG module defined in [I-D.ietf-teas-yang-te] to define additional parameters to enable signaling for RSVP-TE.

1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The terminology for describing YANG data models is found in [RFC7950].

1.2. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

Prefix	YANG module	Reference
yang	ietf-yang-types	[RFC6991]
inet	ietf-inet-types	[RFC6991]
te	ietf-te	[I-D.ietf-teas-yang-te]
rsvp	ietf-rsvp	[I-D.ietf-teas-yang-rsvp]
te-dev	ietf-te-device	[I-D.ietf-teas-yang-te]
te-types	ietf-te-types	[I-D.ietf-teas-yang-te-types]
te-mpls-types	ietf-te-mpls-types	[I-D.ietf-teas-yang-te-types]
rsvp-te	ietf-rsvp-te	this document
rsvp-te-mpls	ietf-rsvp-te-mpls	this document

Table 1: Prefixes and corresponding YANG modules

2. Model Overview

The RSVP-TE generic model augments the RSVP base and extended YANG models defined in [I-D.ietf-teas-yang-rsvp]. It also augments the TE tunnels and interfaces module defined in [I-D.ietf-teas-yang-te] to cover parameters specific to the configuration and management of RSVP-TE interfaces, tunnels and LSP(s).

The RSVP-TE MPLS YANG model augments the RSVP-TE generic model with parameters to configure and manage signaling of MPLS RSVP-TE LSPs. RSVP-TE model augmentation for other dataplane technologies (e.g. OTN or WDM) are outside the scope of this document.

There are three types of configuration and state data nodes in module(s) defined in this document:

- o those augmenting or extending the base RSVP module that is defined in [I-D.ietf-teas-yang-rsvp]
- o those augmenting or extending the base TE module defined in [I-D.ietf-teas-yang-te]
- o those that are specific to the RSVP-TE and RSVP-TE MPLS modules defined in this document.

2.1. Module Relationship

The data pertaining to RSVP-TE in this document is divided into two modules: a technology agnostic RSVP-TE module that holds generic parameters for RSVP-TE applicable to all technologies, and a MPLS technology specific RSVP-TE module that holds parameters specific to MPLS technology.

The relationship between the different modules is shown in Figure 1.

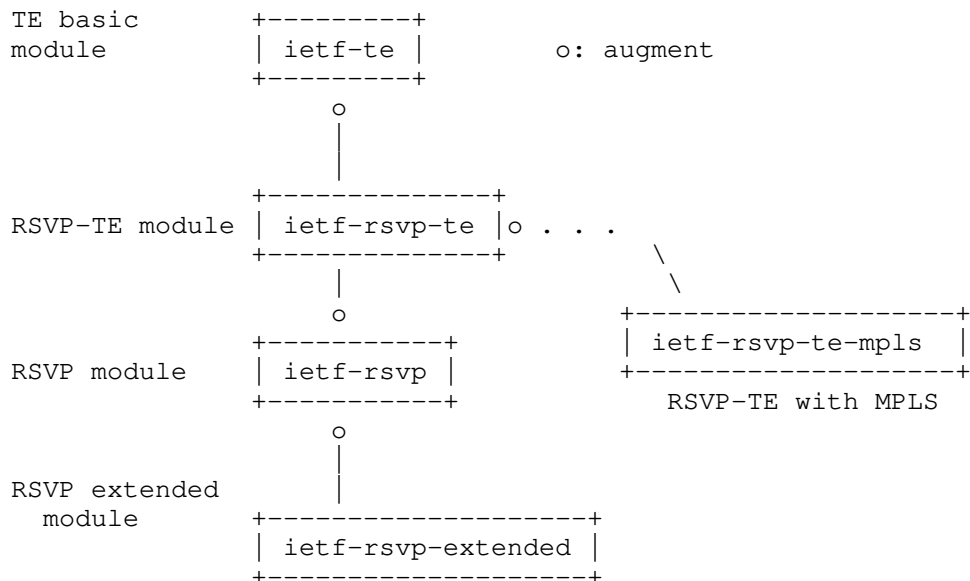


Figure 1: Relationship of RSVP and RSVP-TE modules with other protocol modules

2.2. Model Tree Diagrams

A full tree diagram of the module(s) defined in this document as per the syntax defined in [RFC8340] are given in subsequent sections.

2.2.1. RSVP-TE Model Tree Diagram

Figure 2 shows the YANG tree diagram of the RSVP-TE generic YANG model defined in module `ietf-rsvp-te.yang`.

```

module: ietf-rsvp-te
  augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp:
      +--rw global-soft-preemption!
      +--rw soft-preemption-timeout?  uint16
  augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces:
      +--rw rsvp-te-interface-attributes
  augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces
      /rsvp:interface:
        +--rw rsvp-te-interface-attributes
  
```

```

augment /rt:routing/rt:control-plane-protocols
  /rt:control-plane-protocol/rsvp:rsvp/rsvp:sessions:
    +---ro session-te* [tunnel-endpoint tunnel-id extended-tunnel-id]
      +---ro tunnel-endpoint      inet:ip-address
      +---ro tunnel-id            uint16
      +---ro extended-tunnel-id   inet:ip-address
      +---ro destination-port?    inet:port-number
      +---ro protocol-id?         uint8
      +---ro source?              inet:ip-address
      +---ro destination?         inet:ip-address
      +---ro session-name?        string
      +---ro session-status?      enumeration
      +---ro session-type         identityref
      +---ro psbs
        | +---ro psb* []
        |   +---ro source-port?      inet:port-number
        |   +---ro expires-in?       uint32
        |   +---ro tspec-average-rate?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro tspec-size?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro tspec-peak-rate?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro min-policed-unit?  uint32
        |   +---ro max-packet-size?   uint32
      +---ro rsbs
        | +---ro rsb* []
        |   +---ro source-port?      inet:port-number
        |   +---ro reservation-style  identityref
        |   +---ro expires-in?       uint32
        |   +---ro fspec-average-rate?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro fspec-size?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro fspec-peak-rate?
        |   |   rt-types:bandwidth-ieee-float32
        |   +---ro min-policed-unit?  uint32
        |   +---ro max-packet-size?   uint32
augment /rt:routing/rt:control-plane-protocols
  /rt:control-plane-protocol/rsvp:rsvp/rsvp:neighbors:
augment /te:te/te:tunnels/te:tunnel:
  +---rw lsp-sigaled-name?  string
  +---rw session-attribute*  identityref
  +---rw lsp-attribute*      identityref
  +---rw retry-timer?        uint16
augment /te:te/te:lsps/te:lsp:
  +---ro associated-rsvp-session?  leafref
  +---ro lsp-sigaled-name?         string

```

```

+--ro session-attribute*                identityref
+--ro lsp-attribute*                    identityref
+--ro rsvp-message-type?                identityref
+--ro rsvp-error-code?                  uint8
+--ro rsvp-error-subcode?               uint16
+--ro explicit-route-objects
|
|   +--ro incoming-explicit-route-hop* [index]
|   |
|   |   +--ro index                    uint32
|   |   +--ro (type)?
|   |   |
|   |   |   +--:(numbered-node-hop)
|   |   |   |
|   |   |   |   +--ro numbered-node-hop
|   |   |   |   |
|   |   |   |   |   +--ro node-id      te-node-id
|   |   |   |   |   +--ro hop-type?    te-hop-type
|   |   |   |   +--:(numbered-link-hop)
|   |   |   |   |
|   |   |   |   |   +--ro numbered-link-hop
|   |   |   |   |   |
|   |   |   |   |   |   +--ro link-tp-id    te-tp-id
|   |   |   |   |   |   +--ro hop-type?    te-hop-type
|   |   |   |   |   |   +--ro direction?   te-link-direction
|   |   |   |   +--:(unnumbered-link-hop)
|   |   |   |   |
|   |   |   |   |   +--ro unnumbered-link-hop
|   |   |   |   |   |
|   |   |   |   |   |   +--ro link-tp-id    te-tp-id
|   |   |   |   |   |   +--ro node-id      te-node-id
|   |   |   |   |   |   +--ro hop-type?    te-hop-type
|   |   |   |   |   |   +--ro direction?   te-link-direction
|   |   |   +--:(as-number)
|   |   |   |
|   |   |   |   +--ro as-number-hop
|   |   |   |   |
|   |   |   |   |   +--ro as-number      inet:as-number
|   |   |   |   |   +--ro hop-type?      te-hop-type
|   |   |   +--:(label)
|   |   |   |
|   |   |   |   +--ro label-hop
|   |   |   |   |
|   |   |   |   |   +--ro te-label
|   |   |   |   |   |
|   |   |   |   |   |   +--ro (technology)?
|   |   |   |   |   |   |
|   |   |   |   |   |   |   +--:(generic)
|   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   +--ro generic?
|   |   |   |   |   |   |   |   |
|   |   |   |   |   |   |   |   |   rt-types:generalized-label
|   |   |   |   |   |   +--ro direction?   te-label-direction
|   |   +--ro outgoing-explicit-route-hop* [index]
|   |   |
|   |   |   +--ro index                    uint32
|   |   |   +--ro (type)?
|   |   |   |
|   |   |   |   +--:(numbered-node-hop)
|   |   |   |   |
|   |   |   |   |   +--ro numbered-node-hop
|   |   |   |   |   |
|   |   |   |   |   |   +--ro node-id      te-node-id
|   |   |   |   |   |   +--ro hop-type?    te-hop-type
|   |   |   |   +--:(numbered-link-hop)
|   |   |   |   |
|   |   |   |   |   +--ro numbered-link-hop
|   |   |   |   |   |
|   |   |   |   |   |   +--ro link-tp-id    te-tp-id
|   |   |   |   |   |   +--ro hop-type?    te-hop-type
|   |   |   |   |   |   +--ro direction?   te-link-direction

```

```

+---:(unnumbered-link-hop)
|   +---ro unnumbered-link-hop
|       +---ro link-tp-id      te-tp-id
|       +---ro node-id        te-node-id
|       +---ro hop-type?      te-hop-type
|       +---ro direction?     te-link-direction
+---:(as-number)
|   +---ro as-number-hop
|       +---ro as-number      inet:as-number
|       +---ro hop-type?      te-hop-type
+---:(label)
|   +---ro label-hop
|       +---ro te-label
|           +---ro (technology)?
|               +---:(generic)
|                   +---ro generic?
|                       rt-types:generalized-label
|               +---ro direction?     te-label-direction
+---ro incoming-record-route-subobjects
+---ro incoming-record-route-subobject* [index]
+---ro index                               uint32
+---ro (type)?
+---:(numbered-node-hop)
|   +---ro numbered-node-hop
|       +---ro node-id      te-node-id
|       +---ro flags*       path-attribute-flags
+---:(numbered-link-hop)
|   +---ro numbered-link-hop
|       +---ro link-tp-id    te-tp-id
|       +---ro flags*       path-attribute-flags
+---:(unnumbered-link-hop)
|   +---ro unnumbered-link-hop
|       +---ro link-tp-id    te-tp-id
|       +---ro node-id?     te-node-id
|       +---ro flags*       path-attribute-flags
+---:(label)
|   +---ro label-hop
|       +---ro te-label
|           +---ro (technology)?
|               +---:(generic)
|                   +---ro generic?
|                       rt-types:generalized-label
|               +---ro direction?     te-label-direction
|       +---ro flags*       path-attribute-flags
+---ro outgoing-record-route-subobjects
+---ro outgoing-record-route-subobject* [index]
+---ro index                               uint32
+---ro (type)?

```

```

+---:(numbered-node-hop)
|   +---ro numbered-node-hop
|       +---ro node-id      te-node-id
|       +---ro flags*       path-attribute-flags
+---:(numbered-link-hop)
|   +---ro numbered-link-hop
|       +---ro link-tp-id    te-tp-id
|       +---ro flags*       path-attribute-flags
+---:(unnumbered-link-hop)
|   +---ro unnumbered-link-hop
|       +---ro link-tp-id    te-tp-id
|       +---ro node-id?     te-node-id
|       +---ro flags*       path-attribute-flags
+---:(label)
|   +---ro label-hop
|       +---ro te-label
|           +---ro (technology)?
|               +---:(generic)
|                   +---ro generic?
|                       rt-types:generalized-label
|       +---ro direction?   te-label-direction
|       +---ro flags*       path-attribute-flags
augment /te:te/te-dev:interfaces/te-dev:interface:

```

Figure 2: RSVP-TE model Tree diagram

2.2.2. RSVP-TE MPLS Model Tree Diagram

Figure 5 shows the YANG tree diagram of the RSVP-TE MPLS YANG model defined in module `ietf-rsvp-te-mpls.yang` and that augments RSVP-TE module as well as RSVP and TE YANG modules.

```

module: ietf-rsvp-te-mpls
augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp:
    +---rw rsvp-frr-local-revert-delay?  uint32
augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces:
augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces
    /rsvp:interface:
augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:sessions:
augment /rt:routing/rt:control-plane-protocols
    /rt:control-plane-protocol/rsvp:rsvp/rsvp:neighbors:
augment /te:te/te:tunnels/te:tunnel:
    +---rw session-attribute*  identityref
augment /te:te/te:lsps/te:lsp:

```

```

+---ro session-attribute*   identityref
+---ro backup-info
  +---ro backup-tunnel-name?   string
  +---ro backup-frr-on?        uint8
  +---ro backup-protected-lsp-num?  uint32
augment /te:te/te:tunnels/te:tunnel/te:primary-paths
  /te:primary-path/te:lsps/te:lsp:
+---ro session-attribute*   identityref
+---ro backup-info
  +---ro backup-tunnel-name?   string
  +---ro backup-frr-on?        uint8
  +---ro backup-protected-lsp-num?  uint32
augment /te:te/te:tunnels/te:tunnel/te:secondary-paths
  /te:secondary-path/te:lsps/te:lsp:
+---ro session-attribute*   identityref
+---ro backup-info
  +---ro backup-tunnel-name?   string
  +---ro backup-frr-on?        uint8
  +---ro backup-protected-lsp-num?  uint32
augment /te:te/te-dev:interfaces/te-dev:interface:
+---rw bandwidth-mpls-reservable
+---rw (bandwidth-value)?
  | +---:(absolute)
  | | +---rw absolute-value?   te-packet-types:bandwidth-kbps
  | | +---:(percentage)
  | | | +---rw percent-value?  uint32
+---rw (bc-model-type)?
+---:(bc-model-rdm)
  | +---rw bc-model-rdm
  | | +---rw bandwidth-mpls-constraints
  | | | +---rw maximum-reservable?
  | | | | te-packet-types:bandwidth-kbps
  | | | +---rw bc-value*      uint32
+---:(bc-model-mam)
  | +---rw bc-model-mam
  | | +---rw bandwidth-mpls-constraints
  | | | +---rw maximum-reservable?
  | | | | te-packet-types:bandwidth-kbps
  | | | +---rw bc-value*      uint32
+---:(bc-model-mar)
  | +---rw bc-model-mar
  | | +---rw bandwidth-mpls-constraints
  | | | +---rw maximum-reservable?
  | | | | te-packet-types:bandwidth-kbps
  | | | +---rw bc-value*      uint32
augment /te:te/te-dev:interfaces/te-dev:interface:
+---rw rsvp-te-frr-backups
+---rw (type)?

```

```

+---:(static-tunnel)
|   +---rw static-backups
|       +---rw static-backup* [backup-tunnel-name]
|       +---rw backup-tunnel-name
|           -> /te:te/tunnels/tunnel/name
+---:(auto-tunnel)
    +---rw auto-tunnel-backups
    +---rw auto-backup-protection?      identityref
    +---rw auto-backup-path-computation? identityref

```

Figure 3: RSVP-TE MPLS Tree diagram

2.3. YANG Modules

2.3.1. RSVP-TE YANG Module

The RSVP-TE generic YANG module "ietf-rsvp-te" imports the following modules:

- o ietf-rsvp defined in [I-D.ietf-teas-yang-rsvp]
- o ietf-routing-types defined in [RFC8294]
- o ietf-te-types defined in [I-D.ietf-teas-yang-te-types]
- o ietf-te and ietf-te-dev defined in [I-D.ietf-teas-yang-te]

This module references the following documents:

[I-D.ietf-teas-yang-rsvp], [RFC8349], [I-D.ietf-teas-yang-te], [I-D.ietf-teas-yang-te-types], [RFC2210], [RFC4920], [RFC5420], [RFC7570], [RFC4859].

```

<CODE BEGINS> file "ietf-rsvp-te@2021-02-21.yang"
module ietf-rsvp-te {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-rsvp-te";
  prefix rsvp-te;

  import ietf-rsvp {
    prefix rsvp;
    reference
      "draft-ietf-teas-yang-rsvp: A YANG Data Model for
      Resource Reservation Protocol (RSVP)";
  }
  import ietf-routing {
    prefix rt;
    reference
      "RFC8349: A YANG Data Model for Routing Management";
  }

```

```
}
import ietf-routing-types {
  prefix rt-types;
  reference
    "RFC8294: Common YANG Data Types for the Routing Area";
}
import ietf-te {
  prefix te;
  reference
    "draft-ietf-teas-yang-te: A YANG Data Model for Traffic
    Engineering Tunnels and Interfaces";
}
import ietf-te-device {
  prefix te-dev;
  reference
    "draft-ietf-teas-yang-te: A YANG Data Model for Traffic
    Engineering Tunnels and Interfaces";
}

/* Import TE generic types */

import ietf-te-types {
  prefix te-types;
  reference
    "RFC8776: Common YANG Data Types for Traffic Engineering.";
}
import ietf-inet-types {
  prefix inet;
  reference
    "RFC6991: Common YANG Data Types";
}

organization
  "IETF Traffic Engineering Architecture and Signaling (TEAS)
  Working Group";
contact
  "WG Web:  <http://tools.ietf.org/wg/teas/>
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description

"This module contains the RSVP-TE YANG generic data model.
The model fully conforms to the Network Management Datastore
Architecture (NMDA)."

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set forth in Section 4.c of the IETF Trust's Legal Provisions
Relating to IETF Documents
(<https://trustee.ietf.org/license-info>).
This version of this YANG module is part of RFC XXXX; see
the RFC itself for full legal notices.";

// RFC Ed.: replace XXXX with actual RFC number and remove this
// note.
// RFC Ed.: update the date below with the date of RFC publication
// and remove this note.

```
revision 2021-02-21 {  
  description  
    "A YANG Data Model for RSVP-TE";  
  reference  
    "RFCXXXX: A YANG Data Model for RSVP-TE Protocol";  
}
```

```
identity rsvp-message-type {  
  description  
    "RSVP message types";  
}
```

```
identity rsvp-message-path {  
  base rsvp-message-type;  
  description  
    "RSVP Path message";  
  reference  
    "RFC2205";  
}
```

```
}

identity rsvp-message-resv {
  base rsvp-message-type;
  description
    "RSVP Resv message";
  reference
    "RFC2205";
}

identity rsvp-message-path-err {
  base rsvp-message-type;
  description
    "RSVP Path-Err message";
  reference
    "RFC2205";
}

identity rsvp-message-resv-err {
  base rsvp-message-type;
  description
    "RSVP Resv-Err message";
  reference
    "RFC2205";
}

identity rsvp-message-path-tear {
  base rsvp-message-type;
  description
    "RSVP Path Tear message";
  reference
    "RFC2205";
}

identity rsvp-message-resv-conf {
  base rsvp-message-type;
  description
    "RSVP Resv Confirm message";
  reference
    "RFC2205";
}

identity rsvp-message-srefresh {
  base rsvp-message-type;
  description
    "RSVP SRefresh message";
  reference
    "RFC2961";
}
```

```
    }

    identity rsvp-message-hello {
      base rsvp-message-type;
      description
        "RSVP Hello message";
      reference
        "RFC3209";
    }

    identity rsvp-message-bundle {
      base rsvp-message-type;
      description
        "RSVP Bundle message";
      reference
        "RFC2961";
    }

    identity rsvp-message-notify {
      base rsvp-message-type;
      description
        "RSVP Notify message";
      reference
        "RFC3473";
    }

    /**
     * RSVP-TE LSPs groupings.
     */

    grouping lsp-record-route-information-state {
      description
        "recorded route information grouping";
      container incoming-record-route-subobjects {
        description
          "RSVP recorded route object incoming information";
        list incoming-record-route-subobject {
          when "../te:origin-type != 'ingress'" {
            description
              "Applicable on non-ingress LSPs only";
          }
          key "index";
          ordered-by user;
          description
            "List of RSVP Path record-route objects";
          uses te-types:record-route-state;
        }
      }
    }
  }
```

```
    container outgoing-record-route-subobjects {
      description
        "RSVP recorded route object outgoing information";
      list outgoing-record-route-subobject {
        when "../te:origin-type != 'egress'" {
          description
            "Applicable on non-egress LSPs only";
        }
        key "index";
        ordered-by user;
        description
          "List of RSVP Resv record-route objects";
        uses te-types:record-route-state;
      }
    }
  }

  grouping lsp-explicit-route-information-state {
    description
      "RSVP-TE LSP explicit-route information";
    container explicit-route-objects {
      description
        "Explicit route object information";
      list incoming-explicit-route-hop {
        when "../te:origin-type != 'ingress'" {
          description
            "Applicable on non-ingress LSPs only";
        }
        key "index";
        ordered-by user;
        description
          "List of incoming RSVP Path explicit-route objects";
        leaf index {
          type uint32;
          description
            "Explicit route hop index. The index is used to
            identify an entry in the list. The order of entries
            is defined by the user without relying on key values";
        }
        uses te-types:explicit-route-hop;
      }
      list outgoing-explicit-route-hop {
        when "../te:origin-type != 'egress'" {
          description
            "Applicable on non-egress LSPs only";
        }
        key "index";
        ordered-by user;
      }
    }
  }
}
```

```
    description
      "List of outgoing RSVP Path explicit-route objects";
    leaf index {
      type uint32;
      description
        "Explicit route hop index. The index is used to
         identify an entry in the list. The order of entries
         is defined by the user without relying on key values";
    }
    uses te-types:explicit-route-hop;
  }
}

grouping lsp-attributes-flags {
  description
    "Configuration parameters relating to RSVP-TE LSP
     attribute flags";
  leaf-list lsp-attribute {
    type identityref {
      base te-types:lsp-attributes-flags;
    }
    description
      "RSVP per LSP attributes flags";
    reference
      "RFC4920, RFC5420, RFC7570";
  }
}

grouping lsp-session-attributes-obj-flags {
  description
    "Configuration parameters relating to RSVP-TE LSP
     session attribute flags";
  reference
    "RFC4859: Registry for RSVP-TE Session Flags";
  leaf-list session-attribute {
    when "../session-attribute !=
      'te-types:bandwidth-protection-desired' or
      ../session-attribute !=
      'te-types:soft-preemption-desired'" {
      description
        "Session attributes applicable to generic technologies
         only.";
    }
    type identityref {
      base te-types:session-attributes-flags;
    }
    description

```

```
        "RSVP session attributes flags";
        reference
        "RFC4859: Registry for RSVP-TE Session Flags";
    }
}

grouping lsp-properties {
    description
        "Configuration parameters relating to RSVP-TE LSP
        session attribute flags";
    leaf lsp-signaled-name {
        type string;
        description
            "Sets the session name to use in the session
            attribute object.";
    }
    uses lsp-session-attributes-obj-flags;
    uses lsp-attributes-flags;
}

grouping tunnel-properties {
    description
        "RSVP-TE Tunnel properties grouping";
    leaf retry-timer {
        type uint16 {
            range "1..600";
        }
        units "seconds";
        description
            "sets the time between attempts to establish the
            LSP";
    }
}

/** End of RSVP-TE LSP groupings */
/**
 * RSVP-TE generic global properties.
 */

grouping global-soft-preemption {
    description
        "Configuration for global RSVP-TE soft preemption";
    container global-soft-preemption {
        presence "Enables soft preemption on a node.";
        description
            "Top level container for RSVP-TE soft-preemption";
        leaf soft-preemption-timeout {
            type uint16 {
```

```
        range "0..300";
    }
    units "seconds";
    default "0";
    description
        "Timeout value for soft preemption to revert
         to hard preemption";
    }
}

/** End of RSVP-TE generic global properties. */
/**
 * RSVP-TE interface generic groupings.
 */

grouping rsvp-te-interface-attributes {
    description
        "Top level grouping for RSVP-TE interface properties.";
    container rsvp-te-interface-attributes {
        description
            "Top level container for RSVP-TE interface
             properties";
    }
}

/** End of RSVP-TE generic groupings */
/* RSVP-TE global properties */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp" {
    description
        "RSVP-TE augmentation to RSVP globals";
    uses global-soft-preemption;
}

/* Linkage to the base RSVP all links */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces" {
    description
        "RSVP-TE generic data augmentation pertaining to interfaces";
    uses rsvp-te-interface-attributes;
}

/* Linkage to per RSVP interface */

augment "/rt:routing/rt:control-plane-protocols/"
```

```
    + "rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces/"
    + "rsvp:interface" {
description
  "RSVP-TE generic data augmentation pertaining to specific
  interface";
uses rsvp-te-interface-attributes;
}

/* add augmentation for sessions and neighbors */

augment "/rt:routing/rt:control-plane-protocols/"
  + "rt:control-plane-protocol/rsvp:rsvp/"
  + "rsvp:sessions" {
description
  "RSVP-TE generic data augmentation pertaining to session";
list session-te {
  key "tunnel-endpoint tunnel-id extended-tunnel-id";
  config false;
  description
    "List of RSVP sessions";
  leaf tunnel-endpoint {
    type inet:ip-address;
    description
      "XX";
  }
  leaf tunnel-id {
    type uint16;
    description
      "XX";
  }
  leaf extended-tunnel-id {
    type inet:ip-address;
    description
      "XX";
  }
  uses rsvp:session-attributes;
}
}

augment "/rt:routing/rt:control-plane-protocols/"
  + "rt:control-plane-protocol/rsvp:rsvp/"
  + "rsvp:sessions/session-te/psbs/psb" {
description
  "RSVP-TE generic data augmentation pertaining to session";
/* To be added */
leaf tspec-average-rate {
  type rt-types:bandwidth-ieee-float32;
  units "Bytes per second";
}
```



```
    description
      "Tspec Token Bucket Average Rate";
    reference
      "RFC2210: RSVP with INTSERV";
  }
  leaf tspec-size {
    type rt-types:bandwidth-ieee-float32;
    units "Bytes per second";
    description
      "Tspec Token Bucket Burst Rate";
    reference
      "RFC2210";
  }
  leaf tspec-peak-rate {
    type rt-types:bandwidth-ieee-float32;
    units "Bytes per second";
    description
      "Tspec Token Bucket Peak Data Rate";
    reference
      "RFC2210";
  }
  leaf min-policed-unit {
    type uint32;
    description
      "Tspec Minimum Policed Unit";
    reference
      "RFC2210";
  }
  leaf max-packet-size {
    type uint32;
    description
      "Tspec Maximum Packet Size";
    reference
      "RFC2210";
  }
}

augment "/rt:routing/rt:control-plane-protocols/"
  + "rt:control-plane-protocol/rsvp:rsvp/"
  + "rsvp:sessions/session-te/rsbs/rsb" {
  description
    "RSVP-TE generic data augmentation pertaining to session";
  leaf fspec-average-rate {
    type rt-types:bandwidth-ieee-float32;
    units "Bytes per second";
    description
      "Fspec Token Bucket Average Rate";
    reference
```

```
        "RFC2210";
    }
    leaf fspec-size {
        type rt-types:bandwidth-ieee-float32;
        units "Bytes per second";
        description
            "Fspec Token Bucket Burst Rate";
        reference
            "RFC2210";
    }
    leaf fspec-peak-rate {
        type rt-types:bandwidth-ieee-float32;
        units "Bytes per second";
        description
            "Fspec Token Bucket Peak Data Rate";
        reference
            "RFC2210";
    }
    leaf min-policed-unit {
        type uint32;
        description
            "Fspec Minimum Policed Unit";
        reference
            "RFC2210";
    }
    leaf max-packet-size {
        type uint32;
        description
            "Fspec Maximum Packet Size";
        reference
            "RFC2210";
    }
}

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp/rsvp:neighbors" {
    description
        "RSVP-TE generic data augmentation pertaining to neighbors";
    /* To be added */
}

/**
 * RSVP-TE generic augmentations of generic TE model.
 */
/* TE tunnel augmentation */

augment "/te:te/te:tunnels/te:tunnel" {
    when "/te:te/te:tunnels/te:tunnel"
```

```
    + "/te:primary-paths/te:primary-path"
    + "/te:signaling-type = 'te-types:path-setup-rsvp'" {
  description
    "When the path signaling protocol is RSVP-TE ";
}
description
  "RSVP-TE generic data augmentation pertaining to TE tunnels";
uses lsp-properties;
uses tunnel-properties;
}

/* TE LSP augmentation */

grouping rsvp-te-lsp-error-info {
  description
    "Grouping for RSVP-TE error reporting information";
  leaf rsvp-message-type {
    type identityref {
      base rsvp-message-type;
    }
    description
      "The RSVP message type that delivered the error";
  }
  leaf rsvp-error-code {
    type uint8;
    description
      "RSVP error code";
    reference
      "RFC2205";
  }
  leaf rsvp-error-subcode {
    type uint16;
    description
      "RSVP Error sub-codes";
    reference
      "RFC2205";
  }
}

augment "/te:te/te:lsps/te:lsp" {
  when "/te:te/te:lsps/te:lsp"
    + "/te:signaling-type = 'te-types:path-setup-rsvp'" {
    description
      "When the signaling protocol is RSVP-TE ";
  }
  description
    "RSVP-TE generic data augmentation pertaining to specific TE
    LSP";
```

```
leaf associated-rsvp-session {
  type leafref {
    path "/rt:routing/rt:control-plane-protocols/"
      + "rt:control-plane-protocol/rsvp:rsvp/"
      + "rsvp:sessions/session-te/tunnel-id";
  }
  config false;
  description
    "If the signalling protocol specified for this path is
    RSVP-TE, this leaf provides a reference to the associated
    session within the RSVP-TE protocol sessions list, such
    that details of the signaling can be retrieved.";
}
uses lsp-properties;
uses rsvp-te-lsp-error-info;
uses lsp-explicit-route-information-state;
uses lsp-record-route-information-state;
}

/* TE interface augmentation */

augment "/te:te/te-dev:interfaces/te-dev:interface" {
  description
    "RSVP-TE generic data augmentation pertaining to specific TE
    interface";
}
}
<CODE ENDS>
```

Figure 4: RSVP TE generic YANG module

2.3.2. RSVP-TE MPLS YANG Module

The RSVP-TE MPLS YANG module "ietf-rsvp-te-mpls" imports the following module(s):

- o ietf-rsvp defined in [I-D.ietf-teas-yang-rsvp]
- o ietf-routing-types defined in [RFC8294]
- o ietf-te-mpls-types defined in [I-D.ietf-teas-yang-te-types]
- o ietf-te and ietf-te-dev defined in [I-D.ietf-teas-yang-te]

This module references the following documents:
[I-D.ietf-teas-yang-rsvp], [RFC8349], [I-D.ietf-teas-yang-te-types],
[I-D.ietf-teas-yang-te], [RFC3209].

```
<CODE BEGINS> file "ietf-rsvp-te-mpls@2021-02-21.yang"
module ietf-rsvp-te-mpls {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-rsvp-te-mpls";
  prefix rsvp-te-mpls;

  import ietf-rsvp {
    prefix rsvp;
    reference
      "draft-ietf-teas-yang-rsvp: A YANG Data Model for
      Resource Reservation Protocol (RSVP)";
  }
  import ietf-routing {
    prefix rt;
    reference
      "RFC8349: A YANG Data Model for Routing Management";
  }
  import ietf-te-packet-types {
    prefix te-packet-types;
    reference
      "RFC8776: Common YANG Data Types for Traffic Engineering.";
  }
  import ietf-te-types {
    prefix te-types;
    reference
      "RFC8776: Common YANG Data Types for Traffic Engineering.";
  }
  import ietf-te {
    prefix te;
    reference
      "draft-ietf-teas-yang-te: A YANG Data Model for Traffic
      Engineering Tunnels and Interfaces";
  }
  import ietf-te-device {
    prefix te-dev;
    reference
      "draft-ietf-teas-yang-te: A YANG Data Model for Traffic
      Engineering Tunnels and Interfaces";
  }

  organization
    "IETF Traffic Engineering Architecture and Signaling (TEAS)
    Working Group";
  contact
    "WG Web:  <http://tools.ietf.org/wg/teas/>
    WG List:  <mailto:teas@ietf.org>

    Editor:   Vishnu Pavan Beeram
```

<mailto:vbeeram@juniper.net>

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Editor: Igor Bryskin
<mailto:Igor.Bryskin@huawei.com>

Editor: Himanshu Shah
<mailto:hshah@ciena.com>";

description

"Latest update to MPLS RSVP-TE YANG data model.

The model fully conforms to the Network Management Datastore Architecture (NMDA).

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Relating to IETF Documents
(<https://trustee.ietf.org/license-info>).

This version of this YANG module is part of RFC XXXX; see
the RFC itself for full legal notices.";

// RFC Ed.: replace XXXX with actual RFC number and remove this
// note.
// RFC Ed.: update the date below with the date of RFC publication
// and remove this note.

```
revision 2021-02-21 {  
  description  
    "Update to MPLS RSVP-TE YANG initial revision."  
  reference  
    "RFCXXXX: A YANG Data Model for RSVP-TE Protocol"  
}
```

/* RSVP-TE MPLS LSPs groupings */

```
grouping lsp-attributes-flags-mpls {
```

```
    description
      "Configuration parameters relating to RSVP-TE MPLS LSP
       attribute flags";
  }

  grouping lsp-session-attributes-obj-flags-mpls {
    description
      "Configuration parameters relating to RSVP-TE MPLS LSP
       session attribute flags";
    reference
      "RFC4859: Registry for RSVP-TE Session Flags";
    leaf-list session-attribute {
      when "../session-attribute =
        'te-types:bandwidth-protection-desired' or
        ../session-attribute =
        'te-types:soft-preemption-desired'" {
        description
          "Session attributes applicable to mpls technology";
      }
      type identityref {
        base te-types:session-attributes-flags;
      }
    }
    description
      "RSVP session attributes flags";
    reference
      "RFC4859: Registry for RSVP-TE Session Flags";
  }
}

grouping tunnel-properties-mpls {
  description
    "Top level grouping for LSP properties.";
  uses lsp-session-attributes-obj-flags-mpls;
  uses lsp-attributes-flags-mpls;
}

grouping lsp-properties-mpls {
  description
    "Top level grouping for LSP properties.";
  uses lsp-session-attributes-obj-flags-mpls;
  uses lsp-attributes-flags-mpls;
}

/* End of RSVP-TE MPLS LSPs groupings */
/* MPLS RSVP-TE interface groupings */

grouping rsvp-te-interface-state {
  description
```

```
    "The RSVP-TE interface state grouping";
  leaf over-subscribed-bandwidth {
    type te-packet-types:bandwidth-kbps;
    description
      "The amount of over-subscribed bandwidth on
       the interface";
  }
}

grouping rsvp-te-interface-softpreemption-state {
  description
    "The RSVP-TE interface preemptions state grouping";
  container interface-softpreemption-state {
    description
      "The RSVP-TE interface preemptions state grouping";
    leaf soft-preempted-bandwidth {
      type te-packet-types:bandwidth-kbps;
      description
        "The amount of soft-preempted bandwidth on
         this interface";
    }
    list lsps {
      key "source destination tunnel-id lsp-id "
        + "extended-tunnel-id";
      description
        "List of LSPs that are soft-preempted";
      leaf source {
        type leafref {
          path "/te:te/te:lsps/te:lsp/"
            + "te:source";
        }
        description
          "Tunnel sender address extracted from
           SENDER_TEMPLATE object";
        reference
          "RFC3209";
      }
      leaf destination {
        type leafref {
          path "/te:te/te:lsps/te:lsp/"
            + "te:destination";
        }
        description
          "Tunnel endpoint address extracted from
           SESSION object";
        reference
          "RFC3209";
      }
    }
  }
}
```



```
    leaf tunnel-id {
      type leafref {
        path "/te:te/te:lsps/te:lsp/"
          + "te:tunnel-id";
      }
      description
        "Tunnel identifier used in the SESSION
         that remains constant over the life
         of the tunnel.";
      reference
        "RFC3209";
    }
    leaf lsp-id {
      type leafref {
        path "/te:te/te:lsps/te:lsp/"
          + "te:lsp-id";
      }
      description
        "Identifier used in the SENDER_TEMPLATE
         and the FILTER_SPEC that can be changed
         to allow a sender to share resources with
         itself.";
      reference
        "RFC3209";
    }
    leaf extended-tunnel-id {
      type leafref {
        path "/te:te/te:lsps/te:lsp/"
          + "te:extended-tunnel-id";
      }
      description
        "Extended Tunnel ID of the LSP.";
      reference
        "RFC3209";
    }
    leaf type {
      type leafref {
        path "/te:te/te:lsps/te:lsp/"
          + "te:type";
      }
      description
        "LSP type P2P or P2MP";
    }
  }
}

grouping bandwidth-mpls-constraints {
```

```
description
  "Bandwidth constraints.";
container bandwidth-mpls-constraints {
  description
    "Holds the bandwidth constraints properties";
  leaf maximum-reservable {
    type te-packet-types:bandwidth-kbps;
    description
      "The maximum reservable bandwidth on the
       interface in kbps";
  }
  leaf-list bc-value {
    type uint32 {
      range "0..4294967295";
    }
    max-elements 8;
    description
      "The bandwidth constraint type";
  }
}

grouping bandwidth-constraint-values {
  description
    "Packet bandwidth constraints values";
  choice value-type {
    description
      "Value representation";
    case percentages {
      container perc-values {
        uses bandwidth-mpls-constraints;
        description
          "Percentage values";
      }
    }
    case absolutes {
      container abs-values {
        uses bandwidth-mpls-constraints;
        description
          "Absolute values";
      }
    }
  }
}

grouping bandwidth-mpls-reservable {
  description
    "Interface bandwidth reservable configuration grouping";
```

```
container bandwidth-mpls-reservable {
  description
    "Interface bandwidth reservable container";
  choice bandwidth-value {
    description
      "Reservable bandwidth configuration choice";
    case absolute {
      leaf absolute-value {
        type te-packet-types:bandwidth-kbps;
        description
          "Absolute value of the bandwidth";
      }
    }
    case percentage {
      leaf percent-value {
        type uint32 {
          range "0..4294967295";
        }
        description
          "Percentage reservable bandwidth";
      }
    }
    description
      "The maximum reservable bandwidth on the
      interface";
  }
}
choice bc-model-type {
  description
    "Reservable bandwidth percentage capacity
    values.";
  case bc-model-rdm {
    container bc-model-rdm {
      description
        "Russian Doll Model Bandwidth Constraints.";
      uses bandwidth-mpls-constraints;
    }
  }
  case bc-model-mam {
    container bc-model-mam {
      uses bandwidth-mpls-constraints;
      description
        "Maximum Allocation Model Bandwidth
        Constraints.";
    }
  }
  case bc-model-mar {
    container bc-model-mar {
      uses bandwidth-mpls-constraints;
    }
  }
}
```

```
        description
          "Maximum Allocation with Reservation Model
           Bandwidth Constraints.";
      }
    }
  }
}

/* End of RSVP-TE interface groupings */
/* RSVP-TE FRR groupings */

grouping rsvp-te-frr-auto-tunnel-backup {
  description
    "Auto-tunnel backup configuration grouping";
  leaf auto-backup-protection {
    type identityref {
      base te-packet-types:backup-protection-type;
    }
    default "te-packet-types:backup-protection-node-link";
    description
      "Describes whether the backup should offer
       protection against link, node, or either";
  }
  leaf auto-backup-path-computation {
    type identityref {
      base te-types:path-computation-srlg-type;
    }
    description
      "FRR backup computation type";
  }
}

grouping rsvp-te-frr-backups {
  description
    "Top level container for RSVP-TE FRR backup parameters";
  container rsvp-te-frr-backups {
    description
      "RSVP-TE facility backup properties";
    choice type {
      description
        "FRR backup tunnel type";
      case static-tunnel {
        container static-backups {
          description
            "List of static backups";
          list static-backup {
            key "backup-tunnel-name";
          }
        }
      }
    }
  }
}
```

```
        description
            "List of static backup tunnels that
            protect the RSVP-TE interface.";
        leaf backup-tunnel-name {
            type leafref {
                path "/te:te/te:tunnels/te:tunnel/te:name";
            }
            description
                "FRR Backup tunnel name";
        }
    }
}

case auto-tunnel {
    container auto-tunnel-backups {
        description
            "Auto-tunnel choice";
        uses rsvp-te-frr-auto-tunnel-backup;
    }
}

}

}

grouping lsp-backup-info-state {
    description
        "LSP backup information grouping";
    leaf backup-tunnel-name {
        type string;
        description
            "If an LSP has an FRR backup LSP that can protect it,
            this field identifies the tunnel name of the backup LSP.
            Otherwise, this field is empty.";
    }
    leaf backup-frr-on {
        type uint8;
        description
            "Whether currently this backup is carrying traffic";
    }
    leaf backup-protected-lsp-num {
        type uint32;
        description
            "Number of LSPs protected by this backup";
    }
}

grouping lsp-backup-info {
    description
```

```
        "Backup/bypass LSP related information";
    container backup-info {
        description
            "backup information";
        uses lsp-backup-info-state;
    }
}

/**** End of RSVP-TE FRR backup information ****/

/* RSVP-TE global properties */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp" {
    description
        "RSVP-TE augmentation to RSVP globals";
    leaf rsvp-frr-local-revert-delay {
        type uint32;
        description
            "Time to wait after primary link is restored
            before node attempts local revertive
            procedures.";
    }
}

/* Linkage to the base RSVP all interfaces */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces" {
    description
        "Augmentations for RSVP-TE MPLS all interfaces properties";
    /* To be added */
}

/* Linkage to per RSVP interface */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces/"
    + "rsvp:interface" {
    description
        "Augmentations for RSVP-TE MPLS per interface properties";
    /* To be added */
}

/* add augmentation for sessions neighbors */

augment "/rt:routing/rt:control-plane-protocols/"
    + "rt:control-plane-protocol/rsvp:rsvp/"
```

```
    + "rsvp:sessions" {
      description
        "Augmentation for RSVP-TE MPLS sessions";
      /* To be added */
    }

    augment "/rt:routing/rt:control-plane-protocols/"
      + "rt:control-plane-protocol/rsvp:rsvp/rsvp:neighbors" {
        description
          "Augmentations for RSVP-TE MPLS neighbors properties";
        /* To be added */
      }

    /**
     * Augmentation to TE generic module
     */

    augment "/te:te/te:tunnels/te:tunnel" {
      description
        "Augmentations for RSVP-TE MPLS TE tunnel properties";
      uses tunnel-properties-mpls;
    }

    augment "/te:te/te:lsps/te:lsp" {
      when "/te:te/te:lsps/te:lsp"
        + "/te:signaling-type = 'te-types:path-setup-rsvp'" {
        description
          "When the signaling protocol is RSVP-TE ";
      }
      description
        "RSP-TE MPLS LSP state properties";
      uses lsp-properties-mpls;
      uses lsp-backup-info;
    }

    augment "/te:te/te:tunnels/te:tunnel/te:primary-paths"
      + "/te:primary-path/te:lsps/te:lsp" {
      when "/te:te/te:tunnels/te:tunnel"
        + "/te:secondary-paths/te:secondary-path/"
        + "te:signaling-type = 'te-types:path-setup-rsvp'" {
        description
          "When the signaling protocol is RSVP-TE ";
      }
      description
        "RSVP-TE MPLS LSP state properties";
      uses lsp-properties-mpls;
      uses lsp-backup-info;
    }
  }
```

```

augment "/te:te/te:tunnels/te:tunnel/te:secondary-paths"
  + "/te:secondary-path/te:lsps/te:lsp" {
  when "/te:te/te:tunnels/te:tunnel"
  + "/te:secondary-paths/te:secondary-path/"
  + "te:signaling-type = 'te-types:path-setup-rsvp'" {
    description
      "When the signaling protocol is RSVP-TE ";
  }
  description
    "RSVP-TE MPLS LSP state properties";
  uses lsp-properties-mpls;
  uses lsp-backup-info;
}

augment "/te:te/te-dev:interfaces/te-dev:interface" {
  description
    "RSVP reservable bandwidth configuration properties";
  uses bandwidth-mpls-reservable;
}

augment "/te:te/te-dev:interfaces/te-dev:interface" {
  description
    "RSVP reservable bandwidth configuration properties";
  uses rsvp-te-frr-backups;
}
}
<CODE ENDS>

```

Figure 5: RSVP TE MPLS YANG module

3. IANA Considerations

This document registers the following URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made.

URI: urn:ietf:params:xml:ns:yang:ietf-rsvp-te
 Registrant Contact: The IESG.
 XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-rsvp-te-mpls
 Registrant Contact: The IESG.
 XML: N/A, the requested URI is an XML namespace.

This document registers two YANG modules in the YANG Module Names registry [RFC6020].


```
name:      ietf-rsvp-te
namespace: urn:ietf:params:xml:ns:yang:ietf-rsvp-te
prefix:    rsvp-te
reference:  RFCXXXX

name:      ietf-rsvp-te-mpls
namespace: urn:ietf:params:xml:ns:yang:ietf-rsvp-te-mpls
prefix:    rsvp-te-mpls
reference:  RFCXXXX
```

4. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC8341] provides means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operations and content.

There are a number of data nodes defined in the YANG module(s) defined in this document which are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., <edit-config>) to these data nodes without proper protection can have a negative effect on network operations.

/rt:routing/rt:control-plane-protocols/rt:control-plane-protocol/rsvp:rsvp/globals: The data nodes defined in this document and under this branch are applicable device-wide and can affect all RSVP established sessions. Unauthorized access to this container can potentially cause disruptive event(s) on all established sessions.

/rt:routing/rt:control-plane-protocols/rt:control-plane-protocol/rsvp:rsvp/globals/rsvp:sessions: The data nodes defined in this document and under this branch are applicable to one or all RSVP-TE session(s). Unauthorized access to this container can potentially affect the impacted RSVP session(s).

/rt:routing/rt:control-plane-protocols/rt:control-plane-protocol/rsvp:rsvp/rsvp:interfaces: The data nodes defined in this document and under this branch are applicable to one or all RSVP interfaces. Unauthorized access to this container can potentially affect established session(s) over impacted interface(s).

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A YANG Data Model for Traffic Engineering Tunnels, Label Switched Paths
and Interfaces
draft-ietf-teas-yang-te-29

Abstract

This document defines a YANG data model for the provisioning and management of Traffic Engineering (TE) tunnels, Label Switched Paths (LSPs), and interfaces. The model is divided into YANG modules that classify data into generic, device-specific, technology agnostic, and technology-specific elements.

This model covers data for configuration, operational state, remote procedural calls, and event notifications.

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1. Introduction

YANG [RFC6020] and [RFC7950] is a data modeling language that was introduced to define the contents of a conceptual data store that allows networked devices to be managed using NETCONF [RFC6241]. YANG has proved relevant beyond its initial confines, as bindings to other interfaces (e.g. RESTCONF [RFC8040]) and encoding other than XML (e.g. JSON) are being defined. Furthermore, YANG data models can be used as the basis of implementation for other interfaces, such as CLI and programmatic APIs.

This document describes YANG data model for Traffic Engineering (TE) tunnels, Label Switched Paths (LSPs), and interfaces. The model covers data applicable to generic or device-independent, device-specific, and Multiprotocol Label Switching (MPLS) technology specific.

The document describes a high-level relationship between the modules defined in this document, as well as other external protocol YANG modules. The TE generic YANG data model does not include any data specific to a signaling protocol. It is expected other data plane technology model(s) will augment the TE generic YANG data model.

Also, it is expected other YANG module(s) that model TE signaling protocols, such as RSVP-TE ([RFC3209], [RFC3473]), or Segment-Routing TE (SR-TE) [I-D.ietf-spring-segment-routing-policy] will augment the generic TE YANG module.

2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The following terms are defined in [RFC6241] and are used in this specification:

- * client
- * configuration data

* state data

This document also makes use of the following terminology introduced in the YANG Data Modeling Language [RFC7950]:

* augment

* data model

* data node

2.1. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

Prefix	YANG module	Reference
yang	ietf-yang-types	[RFC6991]
inet	ietf-inet-types	[RFC6991]
rt-types	ietf-routing-types	[RFC8294]
te-types	ietf-te-types	[RFC8776]
te-packet-types	ietf-te-packet-types	[RFC8776]
te	ietf-te	this document
te-dev	ietf-te-device	this document

Table 1: Prefixes and corresponding YANG modules

2.2. Model Tree Diagrams

The tree diagrams extracted from the module(s) defined in this document are given in subsequent sections as per the syntax defined in [RFC8340].

3. Design Considerations

This document describes a generic TE YANG data model that is independent of any dataplane technology. One of the design objectives is to allow specific data plane technology models to reuse the TE generic data model and possibly augment it with technology specific data.

The elements of the generic TE YANG data model, including TE Tunnels, LSPs, and interfaces have leaf(s) that identify the technology layer where they reside. For example, the LSP encoding type can identify the technology associated with a TE Tunnel or LSP.

Also, the generic TE YANG data model does not cover signaling protocol data. The signaling protocol used to instantiate TE LSPs are outside the scope of this document and expected to be covered by augmentations defined in other document(s).

The following other design considerations are taken into account with respect data organization:

- * The generic TE YANG data model 'ietf-te' contains device independent data and can be used to model data off a device (e.g. on a TE controller). The device-specific TE data is defined in module 'ietf-te-device' as shown in Figure 1,
- * In general, minimal elements in the model are designated as "mandatory" to allow freedom to vendors to adapt the data model to their specific product implementation.
- * Suitable defaults are specified for all configurable elements.
- * The model declares a number of TE functions as features that can be optionally supported.

3.1. State Data Organization

The Network Management Datastore Architecture (NMDA) [RFC8342] addresses modeling state data for ephemeral objects. This document adopts the NMDA model for configuration and state data representation as per IETF guidelines for new IETF YANG models.

4. Model Overview

The data models defined in this document cover the core TE features that are commonly supported by different vendor implementations. The support of extended or vendor specific TE feature(s) is expected to be in either augmentations, or deviations to the model defined in this document.

4.1. Module Relationship

The generic TE YANG data model that is defined in "ietf-te.yang" covers the building blocks that are device independent and agnostic of any specific technology or control plane instances. The TE device model defined in "ietf-te-device.yang" augments the generic TE YANG data model and covers data that is specific to a device - for example, attributes of TE interfaces, or TE timers that are local to a TE node.

The TE data model for specific instances of data plane technology exist in a separate YANG module(s) that augment the generic TE YANG data model. For example, the MPLS-TE module "ietf-te-mpls.yang" is defined in another document and augments the TE generic model as shown in Figure 1.

The TE data model for specific instances of signaling protocol are outside the scope of this document and are defined in other documents. For example, the RSVP-TE YANG model augmentation of the TE model is covered in [I-D.ietf-teas-yang-rsvp].

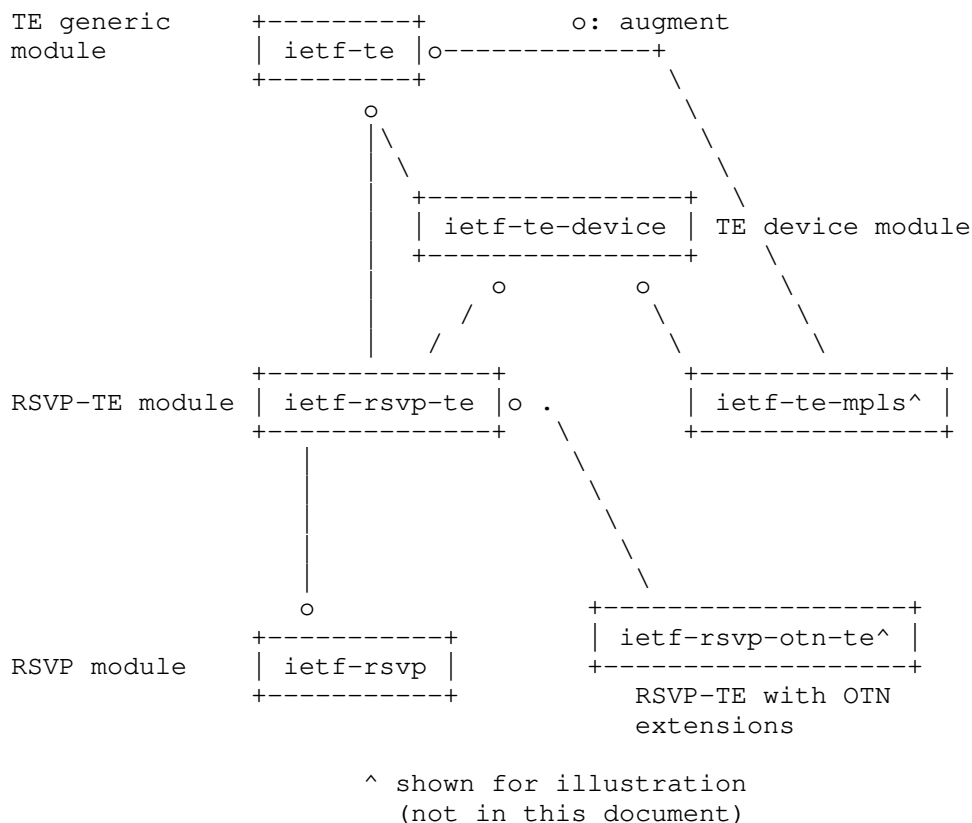


Figure 1: Relationship of TE module(s) with signaling protocol modules

5. TE YANG Model

The generic TE YANG module ('ietf-te') is meant to manage and operate a TE network. This includes creating, modifying and retrieving TE Tunnels, LSPs, and interfaces and their associated attributes (e.g. Administrative-Groups, SRLGs, etc.).

The detailed tree structure is provided in Figure 2.

5.1. Module Structure

The 'ietf-te' uses three main containers grouped under the main 'te' container (see Figure 2). The 'te' container is the top level container in the data model. The presence of the 'te' container enables TE function system wide. Below provides further descriptions of containers that exist under the 'te' top level container.

globals:

The 'globals' container maintains the set of global TE attributes that can be applicable to TE Tunnel(s) and interface(s).

tunnels:

The 'tunnels' container includes the list of TE Tunnels that are instantiated. Refer to Section 5.1.2 for further details on the properties of a TE Tunnel.

lsps:

The 'lsps' container includes the list of TE LSP(s) that are instantiated for TE Tunnels. Refer to Section 5.1.3 for further details on the properties of a TE LSP.

tunnels-path-compute:

A Remote Procedure Call (RPC) to request path computation for a specific TE Tunnel. The RPC allows requesting path computation using atomic and stateless operation. A tunnel may also be configured in 'compute-only' mode to provide stateful path updates - see Section 5.1.2 for further details.

tunnels-action:

An RPC to request a specific action (e.g. reoptimize, or tear-and-setup) to be taken on a specific tunnel or all tunnels.

```
module: ietf-te
  +--rw te!
    +--rw globals
      .
      .
    +--rw tunnels
      .
      .
    +-- lsps
```

```
rpcs:
  +---x tunnels-path-compute
  +---x tunnels-action
```

Figure 2: TE Tunnel model high-level YANG tree view

5.1.1. TE Globals

The 'globals' container covers properties that control TE features behavior system-wide, and its respective state (see Figure 3). The TE globals configuration include:

```

+--rw globals
|   +--rw named-admin-groups
|   |   +--rw named-admin-group* [name]
|   ..
|   +--rw named-srlgs
|   |   +--rw named-srlg* [name] {te-types:named-srlg-groups}?
|   ..
|   +--rw named-path-constraints
|   |   +--rw named-path-constraint* [name]
|   ..

```

Figure 3: TE globals YANG subtree high-level structure

named-admin-groups:

A YANG container for the list of named (extended) administrative groups that may be applied to TE links.

named-srlgs:

A YANG container for the list named Shared Risk Link Groups (SRLGs) that may be applied to TE links.

named-path-constraints:

A YANG container for a list of named path constraints. Each named path constraint is composed of a set of constraints that can be applied during path computation. A named path constraint can be applied to multiple TE Tunnels. Path constraints may also be specified directly under the TE Tunnel. The path constraint specified under the TE Tunnel take precedence over the path constraints derived from the referenced named path constraint. A named path constraint entry can be formed up of the following path constraints:

```

|   +--rw named-path-constraints
|       +--rw named-path-constraint* [name]
|           +--rw name                               string
|           +--rw te-bandwidth
|       // ...
|           +--rw link-protection?                   identityref
|           +--rw setup-priority?                     uint8
|           +--rw hold-priority?                      uint8
|           +--rw signaling-type?                     identityref
|           +--rw path-metric-bounds
|       // ...
|           +--rw path-affinities-values
|       // ...
|           +--rw path-affinity-names
|       // ...
|           +--rw path-srlgs-lists
|       // ...
|           +--rw path-srlgs-names
|       // ...
|           +--rw disjointness?
|               |
|               +--rw te-path-disjointness
|       // ...
|           +--rw explicit-route-objects-always
|       // ...
|               |
|               +--rw route-object-exclude-always* [index]
|               |
|               +--rw route-object-include-exclude* [index]

```

Figure 4: Named path constraints YANG subtree

- o **te-bandwidth**: A YANG container that holds the technology agnostic TE bandwidth constraint.
- o **link-protection**: A YANG leaf that holds the link protection type constraint required for the links to be included in the computed path.
- o **setup/hold priority**: A YANG leaf that holds the LSP setup and hold admission priority as defined in [RFC3209].
- o **signaling-type**: A YANG leaf that holds the LSP setup type, such as RSVP-TE or SR.
- o **path-metric-bounds**: A YANG container that holds the set of metric bounds applicable on the computed TE tunnel path.

- o `path-affinities-values`: A YANG container that holds the set of affinity values and mask to be used during path computation.
- o `path-affinity-names`: A YANG container that holds the set of named affinity constraints and corresponding inclusion or exclusions instruction for each to be used during path computation.
- o `path-srlgs-lists`: A YANG container that holds the set of SRLG values and corresponding inclusion or exclusions instruction to be used during path computation.
- o `path-srlgs-names`: A YANG container that holds the set of named SRLG constraints and corresponding inclusion or exclusions instruction for each to be used during path computation.
- o `disjointness`: The level of resource disjointness constraint that the secondary path of a TE tunnel has to adhere to.
- o `explicit-route-objects-always`: A YANG container that contains two route objects lists:
 - + `'route-object-exclude-always'`: a list of route entries to always exclude from the path computation.
 - + `'route-object-include-exclude'`: a list of route entries to include or exclude in the path computation.

The `'route-object-include-exclude'` is used to configure constraints on which route objects (e.g., nodes, links) are included or excluded in the path computation.

The interpretation of an empty `'route-object-include-exclude'` list depends on the TE Tunnel (end-to-end or Tunnel Segment) and on the specific path, according to the following rules:

1. An empty `'route-object-include-exclude'` list for the primary path of an end-to-end TE Tunnel indicates that there are no route objects to be included or excluded in the path computation.
2. An empty `'route-object-include-exclude'` list for the primary path of a TE Tunnel Segment indicates that no primary LSP is required for that TE Tunnel.

3. An empty 'route-object-include-exclude' list for a reverse path means it always follows the forward path (i.e., the TE Tunnel is co-routed). When the 'route-object-include-exclude' list is not empty, the reverse path is routed independently of the forward path.
4. An empty 'route-object-include-exclude' list for the secondary (forward) path indicates that the secondary path has the same endpoints as the primary path.

5.1.2. TE Tunnels

The 'tunnels' container holds the list of TE Tunnels that are provisioned on devices in the network (see Figure 5).

A TE Tunnel in the list is uniquely identified by a name. When the model is used to manage a specific device, the 'tunnels' list contains the TE Tunnels originating from the specific device. When the model is used to manage a TE controller, the 'tunnels' list contains all TE Tunnels and TE tunnel segments originating from device(s) that the TE controller manages.

The TE Tunnel model allows the configuration and management of the following TE tunnel related objects:

TE Tunnel:

A YANG container of one or more LSPs established between the source and destination TE Tunnel termination points. A TE Tunnel LSP is a connection-oriented service provided by the network layer for the delivery of client data between a source and the destination of the TE Tunnel termination points.

TE Tunnel Segment:

A part of a multi-domain TE Tunnel that is within a specific network domain.

```

+--rw tunnels
|   +--rw tunnel* [name]
|   |   +--rw name                               string
|   |   +--rw alias?                             string
|   |   +--rw identifier?                         uint32
|   |   +--rw color?                             uint32
|   |   +--rw description?                       string
|   |   +--ro operational-state?                 identityref
|   |   +--rw encoding?                         identityref
|   |   +--rw switching-type?                   identityref
|   |   +--rw admin-state?                     identityref
|   |   +--rw reoptimize-timer?                 uint16
|   |   +--rw source?                           te-types:te-node-id
|   |   +--rw destination?                     te-types:te-node-id
|   |   +--rw src-tunnel-tp-id?                 binary
|   |   +--rw dst-tunnel-tp-id?                 binary
|   |   +--rw controller
|   |   |   +--rw protocol-origin?               identityref
|   |   |   +--rw controller-entity-id?         string
|   |   +--rw bidirectional?                   boolean
|   |   +--rw association-objects
|   |   |   +--rw association-object* [association-key]
|   |
|   |   // ..
|   |   |
|   |   +--rw protection
|   |
|   |   // ..
|   |   |
|   |   +--rw restoration
|   |
|   |   // ..
|   |   |
|   |   +--rw te-topology-identifier
|   |
|   |   // ..
|   |   |
|   |   +--rw hierarchy
|   |
|   |   // ..

```

Figure 5: TE Tunnel list YANG subtree structure

The TE Tunnel has a number of attributes that are set directly under the tunnel (see Figure 5). The main attributes of a TE Tunnel are described below:

operational-state:

A YANG leaf that holds the operational state of the tunnel.

name:

A YANG leaf that holds the name of a TE Tunnel. The name of the TE Tunnel uniquely identifies the tunnel within the TE tunnel list. The name of the TE Tunnel can be formatted as a Uniform

Resource Indicator (URI) by including the namespace to ensure uniqueness of the name amongst all the TE Tunnels present on devices and controllers.

alias:

A YANG leaf that holds an alternate name to the TE tunnel. Unlike the TE tunnel name, the alias can be modified at any time during the lifetime of the TE tunnel.

identifier:

A YANG leaf that holds an identifier of the tunnel. This identifier is unique amongst tunnels originated from the same ingress device.

color:

A YANG leaf that holds the color associated with the TE tunnel. The color is used to map or steer services that carry matching color on to the TE tunnel as described in [RFC9012].

encoding/switching:

The 'encoding' and 'switching-type' are YANG leafs that define the specific technology in which the tunnel operates in as described in [RFC3945].

reoptimize-timer:

A YANG leaf to set the interval period for tunnel reoptimization.

source/destination:

YANG leafs that define the tunnel source and destination node endpoints.

src-tunnel-tp-id/dst-tunnel-tp-id:

YANG leafs that hold the identifiers of source and destination TE Tunnel Termination Points (TTPs) [RFC8795] residing on the source and destination nodes. The TTP identifiers are optional on nodes that have a single TTP per node. For example, TTP identifiers are optional for packet (IP/MPLS) routers.

controller:

A YANG container that holds tunnel data relevant to an optional external TE controller that may initiate or control a tunnel. This target node may be augmented by external module(s), for example, to add data for PCEP initiated and/or delegated tunnels.

bidirectional:

A YANG leaf that when present indicates the LSPs of a TE Tunnel are bidirectional and co-routed.

association-objects:

A YANG container that holds the set of associations of the TE Tunnel to other TE Tunnels. Associations at the TE Tunnel level apply to all paths of the TE Tunnel. The TE tunnel associations can be overridden by associations configured directly under the TE Tunnel path.

protection:

A YANG container that holds the TE Tunnel protection properties.

restoration:

A YANG container that holds the TE Tunnel restoration properties.

te-topology-identifier:

A YANG container that holds the topology identifier associated with the topology where paths for the TE tunnel are computed.

```

+--rw hierarchy
|   +--rw dependency-tunnels
|   |   +--rw dependency-tunnel* [name]
|   |   |   +--rw name
|   |   |   |   -> ../../../../tunnels/tunnel/name
|   |   |   +--rw encoding?          identityref
|   |   |   +--rw switching-type?    identityref
|   |   +--rw hierarchical-link
|   |   |   +--rw local-te-node-id?    te-types:te-node-id
|   |   |   +--rw local-te-link-tp-id? te-types:te-tp-id
|   |   |   +--rw remote-te-node-id?   te-types:te-node-id
|   |   +--rw te-topology-identifier
|   |   |   +--rw provider-id?    te-global-id
|   |   |   +--rw client-id?     te-global-id
|   |   |   +--rw topology-id?   te-topology-id

```

Figure 6: TE Tunnel hierarchy YANG subtree

hierarchy:

A YANG container that holds hierarchy related properties of the TE Tunnel (see Figure 6. A TE LSP can be set up in MPLS or Generalized MPLS (GMPLS) networks to be used as a TE links to carry traffic in other (client) networks [RFC6107]. In this case, the model introduces the TE Tunnel hierarchical link endpoint parameters to identify the specific link in the client layer that the underlying TE Tunnel is associated with. The hierarchy container includes the following:

- o dependency-tunnels: A set of hierarchical TE Tunnels provisioned or to be provisioned in the immediate lower layer that this TE tunnel depends on for multi-layer path computation. A dependency TE Tunnel is provisioned if and only if it is used (selected by path computation) at least by one client layer TE Tunnel. The TE link in the client layer network topology supported by a dependent TE Tunnel is dynamically created only when the dependency TE Tunnel is actually provisioned.
- o hierarchical-link: A YANG container that holds the identity of the hierarchical link (in the client layer) that is supported by this TE Tunnel. The endpoints of the hierarchical link are defined by TE tunnel source and destination node endpoints. The hierarchical link can be identified by its source and destination link termination point identifiers.

5.1.2.1. TE Tunnel Paths

The TE Tunnel can be configured with a set of paths that define the tunnel forward and reverse paths as described in Figure 7. Moreover, a primary path can be specified a set of candidate secondary paths that can be visited to support path protection. The following describe further the list of paths associated with a TE Tunnel.

```

|      +--rw primary-paths
|      |   +--rw primary-path* [name]
|      |   |   +--rw name
|      |   |   |   string
|  // ..
|      |   +
|      |   +--rw primary-reverse-path
|      |   |   +--rw name?
|      |   |   |   string
|  // ..
|      |   |
|      |   |   +--rw candidate-secondary-reverse-paths
|      |   |   |   +--rw candidate-secondary-reverse-path*
|      |   |   |   |   [secondary-path]
|      |   |   |   |   +--rw secondary-path
|      |   |   |   |   |   leafref
|      |   |   +--rw candidate-secondary-paths
|      |   |   |   +--rw candidate-secondary-path* [secondary-path]
|      |   |   |   |   +--rw secondary-path
|      |   |   |   |   |   leafref
|      |   |   |   |   +--ro active?
|      |   |   |   |   |   boolean
|
|      +--rw secondary-paths
|      |   +--rw secondary-path* [name]
|      |   |   +--rw name
|      |   |   |   string
|  // ..
|      +--rw secondary-reverse-paths
|      |   +--rw secondary-reverse-path* [name]
|      |   |   +--rw name
|      |   |   |   string

```

Figure 7: TE Tunnel paths YANG tree structure

primary-paths:

A YANG container that holds the list of primary paths. A primary path is identified by 'name'. A primary path is selected from the list to instantiate a primary forwarding LSP for the tunnel. The list of primary paths is visited by order of preference. A primary path has the following attributes:

- primary-reverse-path: A YANG container that holds properties of the primary reverse path. The reverse path is applicable to bidirectional TE Tunnels.
- candidate-secondary-paths: A YANG container that holds a list of candidate secondary paths which may be used for the primary path to support path protection. The candidate secondary path(s) reference path(s) from the tunnel secondary paths list. The preference of the secondary paths is specified within the list and dictates the order of visiting the secondary path from the list. The attributes of a secondary path can be defined

separately from the primary path. The attributes of a secondary path will be inherited from the associated 'active' primary when not explicitly defined for the secondary path.

secondary-paths:

A YANG container that holds the set of secondary paths. A secondary path is identified by 'name'. A secondary path can be referenced from the TE Tunnel's 'candidate-secondary-path' list. A secondary path contains attributes similar to a primary path.

secondary-reverse-paths:

A YANG container that holds the set of secondary reverse paths. A secondary reverse path is identified by 'name'. A secondary reverse path can be referenced from the TE Tunnel's 'candidate-secondary-reverse-paths' list. A secondary reverse path contains attributes similar to a primary path.

The following set common path attributes are shared for primary forward and reverse primary and secondary paths:

compute-only:

A path of TE Tunnel is, by default, provisioned so that it can be instantiated in forwarding to carry traffic as soon as a valid path is computed. In some cases, a TE path may be provisioned for the only purpose of computing a path and reporting it without the need to instantiate the LSP or commit any resources. In such a case, the path is configured in 'compute-only' mode to distinguish it from the default behavior. A 'compute-only' path is configured as a usual with the associated per path constraint(s) and properties on a device or TE controller. The device or TE controller computes the feasible path(s) subject to configured constraints. A client may query the 'compute-only' computed path properties 'on-demand', or alternatively, can subscribe to be notified of computed path(s) and whenever the path properties change.

use-path-computation:

A YANG leaf that indicates whether or not path computation is to be used for a specified path.

lockdown:

A YANG leaf that when set indicates the existing path should not be reoptimized after a failure on any of its traversed links.

te-topology-identifier:

A YANG container that holds the topology identifier associated with the tunnel.

optimizations:

a YANG container that holds the optimization objectives that path computation will use to select a path.

computed-paths-properties: > A YANG container that holds properties for the list of computed paths.

computed-path-error-infos:

A YANG container that holds a list of errors related to the path.

lsps:

a YANG container that holds a list of LSPs that are instantiated for this specific path.

5.1.3. TE LSPs

The 'lsps' container includes the set of TE LSP(s) that are instantiated. A TE LSP is identified by a 3-tuple ('tunnel-name', 'node', 'lsp-id').

When the model is used to manage a specific device, the 'lsps' list contains all TE LSP(s) that traverse the device (including ingressing, transiting and egressing the device).

When the model is used to manage a TE controller, the 'lsps' list contains all TE LSP(s) that traverse all network devices (including ingressing, transiting and egressing the device) that the TE controller manages.

5.2. Tree Diagram

Figure 8 shows the tree diagram of the generic TE YANG model defined in modules 'ietf-te.yang'.


```

module: ietf-te
+--rw te!
  +--rw globals
    +--rw named-admin-groups
      +--rw named-admin-group* [name]
        {te-types:extended-admin-groups,te-types:named-extend
ed-admin-groups}?
        +--rw name string
        +--rw bit-position? uint32
    +--rw named-srlgs
      +--rw named-srlg* [name] {te-types:named-srlg-groups}?
        +--rw name string
        +--rw value? te-types:srlg
        +--rw cost? uint32
    +--rw named-path-constraints
      +--rw named-path-constraint* [name]
        {te-types:named-path-constraints}?
        +--rw name string
        +--rw te-bandwidth
          +--rw (technology)?
            +--:(generic)
              +--rw generic? te-bandwidth
        +--rw link-protection? identityref
        +--rw setup-priority? uint8
        +--rw hold-priority? uint8
        +--rw signaling-type? identityref
        +--rw path-metric-bounds
          +--rw path-metric-bound* [metric-type]
            +--rw metric-type identityref
            +--rw upper-bound? uint64
        +--rw path-affinities-values
          +--rw path-affinities-value* [usage]
            +--rw usage identityref
            +--rw value? admin-groups
        +--rw path-affinity-names
          +--rw path-affinity-name* [usage]
            +--rw usage identityref
            +--rw affinity-name* [name]
              +--rw name string
        +--rw path-srlgs-lists
          +--rw path-srlgs-list* [usage]
            +--rw usage identityref
            +--rw values* srlg
        +--rw path-srlgs-names
          +--rw path-srlgs-name* [usage]
            +--rw usage identityref
            +--rw names* string
        +--rw disjointness?

```

```

    te-path-disjointness
+--rw explicit-route-objects-always
+--rw route-object-exclude-always* [index]
+--rw index                               uint32
+--rw (type)?
+--:(numbered-node-hop)
+--rw numbered-node-hop
+--rw node-id         te-node-id
+--rw hop-type?       te-hop-type
+--:(numbered-link-hop)
+--rw numbered-link-hop
+--rw link-tp-id       te-tp-id
+--rw hop-type?       te-hop-type
+--rw direction?      te-link-direction
+--:(unnumbered-link-hop)
+--rw unnumbered-link-hop
+--rw link-tp-id       te-tp-id
+--rw node-id         te-node-id
+--rw hop-type?       te-hop-type
+--rw direction?      te-link-direction
+--:(as-number)
+--rw as-number-hop
+--rw as-number        inet:as-number
+--rw hop-type?       te-hop-type
+--:(label)
+--rw label-hop
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
+--rw direction?      rt-types:generalized-label
+--rw direction?      te-label-direction
+--rw route-object-include-exclude* [index]
+--rw explicit-route-usage?            identityref
+--rw index                             uint32
+--rw (type)?
+--:(numbered-node-hop)
+--rw numbered-node-hop
+--rw node-id         te-node-id
+--rw hop-type?       te-hop-type
+--:(numbered-link-hop)
+--rw numbered-link-hop
+--rw link-tp-id       te-tp-id
+--rw hop-type?       te-hop-type
+--rw direction?      te-link-direction
+--:(unnumbered-link-hop)
+--rw unnumbered-link-hop

```

```

+---rw link-tp-id      te-tp-id
+---rw node-id         te-node-id
+---rw hop-type?       te-hop-type
+---rw direction?      te-link-direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number        inet:as-number
+---rw hop-type?        te-hop-type
+---:(label)
+---rw label-hop
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw direction?      rt-types:generalized-label
+---rw direction?      te-label-direction
+---:(srlg)
+---rw srlg
+---rw srlg?           uint32
+---rw path-in-segment!
+---rw label-restrictions
+---rw label-restriction* [index]
+---rw restriction?     enumeration
+---rw index            uint32
+---rw label-start
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw direction?      rt-types:generalized-label
+---rw direction?      te-label-direction
+---rw label-end
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw direction?      rt-types:generalized-label
+---rw direction?      te-label-direction
+---rw label-step
+---rw (technology)?
+---:(generic)
+---rw generic?        int32
+---rw range-bitmap?    yang:hex-string
+---rw path-out-segment!
+---rw label-restrictions

```

```

        +---rw label-restriction* [index]
            +---rw restriction?    enumeration
            +---rw index           uint32
            +---rw label-start
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?
                        te-label-direction
            +---rw label-end
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?
                        te-label-direction
            +---rw label-step
                +---rw (technology)?
                    +---:(generic)
                        +---rw generic?    int32
            +---rw range-bitmap?    yang:hex-string
+---rw tunnels
    +---rw tunnel* [name]
        +---rw name                string
        +---rw alias?              string
        +---rw identifier?         uint32
        +---rw color?              uint32
        +---rw description?        string
        +---rw admin-state?        identityref
        +---ro operational-state?   identityref
        +---rw encoding?           identityref
        +---rw switching-type?     identityref
        +---rw source?             te-types:te-node-id
        +---rw destination?        te-types:te-node-id
        +---rw src-tunnel-tp-id?   binary
        +---rw dst-tunnel-tp-id?   binary
        +---rw bidirectional?      boolean
        +---rw controller
            +---rw protocol-origin? identityref
            +---rw controller-entity-id? string
        +---rw reoptimize-timer?   uint16
        +---rw association-objects
            +---rw association-object* [association-key]
                +---rw association-key    string
                +---rw type?              identityref

```

```

+--rw id?                               uint16
+--rw source
  +--rw id?      te-gen-node-id
  +--rw type?    enumeration
+--rw association-object-extended* [association-key]
  +--rw association-key    string
  +--rw type?              identityref
  +--rw id?                uint16
  +--rw source
    +--rw id?      te-gen-node-id
    +--rw type?    enumeration
  +--rw global-source?    uint32
  +--rw extended-id?      yang:hex-string
+--rw protection
  +--rw enable?                                boolean
  +--rw protection-type?                        identityref
  +--rw protection-reversion-disable?          boolean
  +--rw hold-off-time?                          uint32
  +--rw wait-to-revert?                         uint16
  +--rw aps-signal-id?                          uint8
+--rw restoration
  +--rw enable?                                boolean
  +--rw restoration-type?                      identityref
  +--rw restoration-scheme?                    identityref
  +--rw restoration-reversion-disable?          boolean
  +--rw hold-off-time?                          uint32
  +--rw wait-to-restore?                        uint16
  +--rw wait-to-revert?                        uint16
+--rw te-topology-identifier
  +--rw provider-id?    te-global-id
  +--rw client-id?      te-global-id
  +--rw topology-id?    te-topology-id
+--rw te-bandwidth
  +--rw (technology)?
    +--:(generic)
      +--rw generic?    te-bandwidth
+--rw link-protection?                identityref
+--rw setup-priority?                  uint8
+--rw hold-priority?                   uint8
+--rw signaling-type?                  identityref
+--rw hierarchy
  +--rw dependency-tunnels
    +--rw dependency-tunnel* [name]
      +--rw name
        -> /te/tunnels/tunnel/name
      +--rw encoding?                identityref
      +--rw switching-type?          identityref
+--rw hierarchical-link

```

```

+--rw local-te-node-id?          te-types:te-node-id
+--rw local-te-link-tp-id?       te-types:te-tp-id
+--rw remote-te-node-id?        te-types:te-node-id
+--rw te-topology-identifier
  +--rw provider-id?            te-global-id
  +--rw client-id?              te-global-id
  +--rw topology-id?            te-topology-id
+--rw primary-paths
  +--rw primary-path* [name]
    +--rw name                  string
    +--rw path-computation-method? identityref
    +--rw path-computation-server
      +--rw id?                  te-gen-node-id
      +--rw type?                enumeration
    +--rw compute-only?          empty
    +--rw use-path-computation?  boolean
    +--rw lockdown?              empty
    +--rw path-scope?            identityref
    +--rw preference?            uint8
    +--rw k-requested-paths?     uint8
    +--rw association-objects
      +--rw association-object* [association-key]
        +--rw association-key    string
        +--rw type?              identityref
        +--rw id?                uint16
        +--rw source
          +--rw id?              te-gen-node-id
          +--rw type?            enumeration
      +--rw association-object-extended*
        [association-key]
        +--rw association-key    string
        +--rw type?              identityref
        +--rw id?                uint16
        +--rw source
          +--rw id?              te-gen-node-id
          +--rw type?            enumeration
        +--rw global-source?     uint32
        +--rw extended-id?       yang:hex-string
+--rw optimizations
  +--rw (algorithm)?
    +--:(metric) {path-optimization-metric}?
      +--rw optimization-metric* [metric-type]
        +--rw metric-type
          identityref
        +--rw weight?
          uint8
        +--rw explicit-route-exclude-objects
        +--rw route-object-exclude-object*

```

[illegible]

```

+---rw explicit-route-include-objects
+---rw route-object-include-object*
    [index]
+---rw index
    |   uint32
+---rw (type)?
+---:(numbered-node-hop)
    +---rw numbered-node-hop
        +---rw node-id
            |   te-node-id
        +---rw hop-type?
            |   te-hop-type
+---:(numbered-link-hop)
    +---rw numbered-link-hop
        +---rw link-tp-id
            |   te-tp-id
        +---rw hop-type?
            |   te-hop-type
        +---rw direction?
            |   te-link-direction
+---:(unnumbered-link-hop)
    +---rw unnumbered-link-hop
        +---rw link-tp-id
            |   te-tp-id
        +---rw node-id
            |   te-node-id
        +---rw hop-type?
            |   te-hop-type
        +---rw direction?
            |   te-link-direction
+---:(as-number)
    +---rw as-number-hop
        +---rw as-number
            |   inet:as-number
        +---rw hop-type?
            |   te-hop-type
+---:(label)
    +---rw label-hop
        +---rw te-label
            +---rw (technology)?
                +---:(generic)
                    +---rw generic?
                        |   rt-types:ge
neralized-label
n
+---rw tiebreakers

```



```

    +---rw tiebreaker* [tiebreaker-type]
    +---rw tiebreaker-type identityref
+---:(objective-function)
    {path-optimization-objective-function}?
    +---rw objective-function
    +---rw objective-function-type?
        identityref
+---rw named-path-constraint? leafref
    {te-types:named-path-constraints}?
+---rw te-bandwidth
    +---rw (technology)?
    +---:(generic)
        +---rw generic? te-bandwidth
+---rw link-protection? identityref
+---rw setup-priority? uint8
+---rw hold-priority? uint8
+---rw signaling-type? identityref
+---rw path-metric-bounds
    +---rw path-metric-bound* [metric-type]
    +---rw metric-type identityref
    +---rw upper-bound? uint64
+---rw path-affinities-values
    +---rw path-affinities-value* [usage]
    +---rw usage identityref
    +---rw value? admin-groups
+---rw path-affinity-names
    +---rw path-affinity-name* [usage]
    +---rw usage identityref
    +---rw affinity-name* [name]
    +---rw name string
+---rw path-srlgs-lists
    +---rw path-srlgs-list* [usage]
    +---rw usage identityref
    +---rw values* srlg
+---rw path-srlgs-names
    +---rw path-srlgs-name* [usage]
    +---rw usage identityref
    +---rw names* string
+---rw disjointness?
    te-path-disjointness
+---rw explicit-route-objects-always
    +---rw route-object-exclude-always* [index]
    +---rw index uint32
    +---rw (type)?
    +---:(numbered-node-hop)
        +---rw numbered-node-hop
        +---rw node-id te-node-id
        +---rw hop-type? te-hop-type

```

bel

```

+---:(numbered-link-hop)
|   +---rw numbered-link-hop
|       +---rw link-tp-id      te-tp-id
|       +---rw hop-type?      te-hop-type
|       +---rw direction?     te-link-direction
+---:(unnumbered-link-hop)
|   +---rw unnumbered-link-hop
|       +---rw link-tp-id      te-tp-id
|       +---rw node-id        te-node-id
|       +---rw hop-type?      te-hop-type
|       +---rw direction?     te-link-direction
+---:(as-number)
|   +---rw as-number-hop
|       +---rw as-number      inet:as-number
|       +---rw hop-type?     te-hop-type
+---:(label)
|   +---rw label-hop
|       +---rw te-label
|           +---rw (technology)?
|               +---:(generic)
|                   +---rw generic?
|                       rt-types:generalized-la
|
|       +---rw direction?
|           te-label-direction
+---rw route-object-include-exclude* [index]
+---rw explicit-route-usage?      identityref
+---rw index                      uint32
+---rw (type)?
+---:(numbered-node-hop)
|   +---rw numbered-node-hop
|       +---rw node-id      te-node-id
|       +---rw hop-type?    te-hop-type
+---:(numbered-link-hop)
|   +---rw numbered-link-hop
|       +---rw link-tp-id    te-tp-id
|       +---rw hop-type?    te-hop-type
|       +---rw direction?   te-link-direction
+---:(unnumbered-link-hop)
|   +---rw unnumbered-link-hop
|       +---rw link-tp-id    te-tp-id
|       +---rw node-id      te-node-id
|       +---rw hop-type?    te-hop-type
|       +---rw direction?   te-link-direction
+---:(as-number)
|   +---rw as-number-hop
|       +---rw as-number    inet:as-number
|       +---rw hop-type?    te-hop-type

```

bel

```

+---:(label)
|   +---rw label-hop
|       +---rw te-label
|           +---rw (technology)?
|               +---:(generic)
|                   +---rw generic?
|                       rt-types:generalized-la
|
|       +---rw direction?
|           te-label-direction
+---:(srlg)
|   +---rw srlg
|       +---rw srlg?    uint32
+---rw path-in-segment!
+---rw label-restrictions
+---rw label-restriction* [index]
+---rw restriction?    enumeration
+---rw index            uint32
+---rw label-start
|   +---rw te-label
|       +---rw (technology)?
|           +---:(generic)
|               +---rw generic?
|                   rt-types:generalized-label
|       +---rw direction?
|           te-label-direction
+---rw label-end
|   +---rw te-label
|       +---rw (technology)?
|           +---:(generic)
|               +---rw generic?
|                   rt-types:generalized-label
|       +---rw direction?
|           te-label-direction
+---rw label-step
|   +---rw (technology)?
|       +---:(generic)
|           +---rw generic?    int32
+---rw range-bitmap?    yang:hex-string
+---rw path-out-segment!
+---rw label-restrictions
+---rw label-restriction* [index]
+---rw restriction?    enumeration
+---rw index            uint32
+---rw label-start
|   +---rw te-label
|       +---rw (technology)?
|           +---:(generic)

```

```

|         |       +---rw generic?
|         |           rt-types:generalized-label
+---rw direction?
|             te-label-direction
+---rw label-end
|     +---rw te-label
|         +---rw (technology)?
|             +---:(generic)
|                 +---rw generic?
|                     rt-types:generalized-label
+---rw direction?
|             te-label-direction
+---rw label-step
|     +---rw (technology)?
|         +---:(generic)
|             +---rw generic?      int32
+---rw range-bitmap?    yang:hex-string
+---ro computed-paths-properties
+--ro computed-path-properties* [k-index]
+--ro k-index              uint8
+--ro path-properties
+--ro path-metric* [metric-type]
|   +--ro metric-type        identityref
|   +--ro accumulative-value? uint64
+--ro path-affinities-values
|   +--ro path-affinities-value* [usage]
|       +--ro usage          identityref
|       +--ro value?         admin-groups
+--ro path-affinity-names
|   +--ro path-affinity-name* [usage]
|       +--ro usage            identityref
|       +--ro affinity-name* [name]
|           +--ro name          string
+--ro path-srlgs-lists
|   +--ro path-srlgs-list* [usage]
|       +--ro usage            identityref
|       +--ro values*          srlg
+--ro path-srlgs-names
|   +--ro path-srlgs-name* [usage]
|       +--ro usage            identityref
|       +--ro names*          string
+--ro path-route-objects
|   +--ro path-route-object* [index]
|       +--ro index
|           |                uint32
+--ro (type)?
|   +--:(numbered-node-hop)
|       +--ro numbered-node-hop

```

```

+--ro node-id      te-node-id
+--ro hop-type?
    te-hop-type
+--:(numbered-link-hop)
+--ro numbered-link-hop
+--ro link-tp-id    te-tp-id
+--ro hop-type?
    |
    te-hop-type
+--ro direction?
    te-link-direction
+--:(unnumbered-link-hop)
+--ro unnumbered-link-hop
+--ro link-tp-id    te-tp-id
+--ro node-id
    |
    te-node-id
+--ro hop-type?
    |
    te-hop-type
+--ro direction?
    te-link-direction
+--:(as-number)
+--ro as-number-hop
+--ro as-number
    |
    inet:as-number
+--ro hop-type?
    te-hop-type
+--:(label)
+--ro label-hop
+--ro te-label
    +--ro (technology)?
        |
        +--:(generic)
        |
        +--ro generic?
            rt-types:gener
+--ro direction?
    te-label-direction
+--ro te-bandwidth
+--ro (technology)?
    +--:(generic)
    +--ro generic?
        te-bandwidth
+--ro disjointness-type?
    te-types:te-path-disjointness
+--ro computed-path-error-infos
+--ro computed-path-error-info* []
+--ro error-description?
    string
+--ro error-timestamp?
    yang:date-and-time
+--ro error-reason?
    identityref
+--ro lsp-provisioning-error-infos
+--ro lsp-provisioning-error-info* []

```

```

    +--ro error-description?  string
    +--ro error-timestamp?    yang:date-and-time
    +--ro error-node-id?      te-types:te-node-id
    +--ro error-link-id?      te-types:te-tp-id
    +--ro lsp-id?             uint16
+--ro lsps
  +--ro lsp* [node lsp-id]
    +--ro tunnel-name?
      |      -> /te/lsps/lsp/tunnel-name
    +--ro node          -> /te/lsps/lsp/node
    +--ro lsp-id        -> /te/lsps/lsp/lsp-id
+--rw primary-reverse-path
  +--rw name?                                string
  +--rw path-computation-method?
    |      identityref
  +--rw path-computation-server
    |      +--rw id?      te-gen-node-id
    |      +--rw type?    enumeration
  +--rw compute-only?                        empty
  +--rw use-path-computation?
    |      boolean
  +--rw lockdown?                            empty
  +--ro path-scope?
    |      identityref
  +--rw association-objects
    +--rw association-object* [association-key]
      |      +--rw association-key  string
      |      +--rw type?            identityref
      |      +--rw id?              uint16
      |      +--rw source
      |        |      +--rw id?      te-gen-node-id
      |        |      +--rw type?    enumeration
      +--rw association-object-extended*
        |      [association-key]
        |      +--rw association-key  string
        |      +--rw type?            identityref
        |      +--rw id?              uint16
        |      +--rw source
        |        |      +--rw id?      te-gen-node-id
        |        |      +--rw type?    enumeration
        |      +--rw global-source?   uint32
        |      +--rw extended-id?     yang:hex-string
  +--rw optimizations
    +--rw (algorithm)?
      +--:(metric) {path-optimization-metric}?
        |      +--rw optimization-metric* [metric-type]
        |        |      +--rw metric-type
        |        |      |      identityref

```

```

+---rw weight?
|   uint8
+---rw explicit-route-exclude-objects
|   +---rw route-object-exclude-object*
|       [index]
|       +---rw index
|           |   uint32
|       +---rw (type)?
|           +---:(numbered-node-hop)
|               +---rw numbered-node-hop
|                   +---rw node-id
|                       |   te-node-id
|                   +---rw hop-type?
|                       |   te-hop-type
|           +---:(numbered-link-hop)
|               +---rw numbered-link-hop
|                   +---rw link-tp-id
|                       |   te-tp-id
|                   +---rw hop-type?
|                       |   te-hop-type
|                   +---rw direction?
|                       |   te-link-direction
|           +---:(unnumbered-link-hop)
|               +---rw unnumbered-link-hop
|                   +---rw link-tp-id
|                       |   te-tp-id
|                   +---rw node-id
|                       |   te-node-id
|                   +---rw hop-type?
|                       |   te-hop-type
|                   +---rw direction?
|                       |   te-link-direction
|           +---:(as-number)
|               +---rw as-number-hop
|                   +---rw as-number
|                       |   inet:as-number
|                   +---rw hop-type?
|                       |   te-hop-type
|           +---:(label)
|               +---rw label-hop
|                   +---rw te-label
|                       +---rw (technology)?
|                           +---:(generic)
|                               +---rw generic?
|                                   rt-types
:generalized-label
+---rw direction?
    te-label-direc

```

tion

```

+---:(srlg)
+---rw srlg
+---rw srlg?   uint32
+---rw explicit-route-include-objects
+---rw route-object-include-object*
+---rw index
+---rw (type)?
+---:(numbered-node-hop)
+---rw numbered-node-hop
+---rw node-id
+---rw node-id
+---rw hop-type?
+---rw hop-type
+---:(numbered-link-hop)
+---rw numbered-link-hop
+---rw link-tp-id
+---rw link-tp-id
+---rw hop-type?
+---rw hop-type
+---rw direction?
+---rw direction
+---:(unnumbered-link-hop)
+---rw unnumbered-link-hop
+---rw link-tp-id
+---rw link-tp-id
+---rw node-id
+---rw node-id
+---rw hop-type?
+---rw hop-type
+---rw direction?
+---rw direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number
+---rw as-number
+---rw hop-type?
+---rw hop-type
+---:(label)
+---rw label-hop
+---rw te-label
+---rw (technology)?
+---rw (generic)
+---rw generic?
+---rw generic
rt-types
:generalized-label

```



```

        +---rw direction?
            te-label-direct
tion
        +---rw tiebreakers
            +---rw tiebreaker* [tiebreaker-type]
                +---rw tiebreaker-type
                    identityref
        +---:(objective-function)
            {path-optimization-objective-function
}?:
        +---rw objective-function
            +---rw objective-function-type?
                identityref
        +---rw named-path-constraint? leafref
            {te-types:named-path-constraints}?
        +---rw te-bandwidth
            +---rw (technology)?
                +---:(generic)
                    +---rw generic? te-bandwidth
        +---rw link-protection?
            identityref
        +---rw setup-priority? uint8
        +---rw hold-priority? uint8
        +---rw signaling-type?
            identityref
        +---rw path-metric-bounds
            +---rw path-metric-bound* [metric-type]
                +---rw metric-type identityref
                +---rw upper-bound? uint64
        +---rw path-affinities-values
            +---rw path-affinities-value* [usage]
                +---rw usage identityref
                +---rw value? admin-groups
        +---rw path-affinity-names
            +---rw path-affinity-name* [usage]
                +---rw usage identityref
                +---rw affinity-name* [name]
                    +---rw name string
        +---rw path-srlgs-lists
            +---rw path-srlgs-list* [usage]
                +---rw usage identityref
                +---rw values* srlg
        +---rw path-srlgs-names
            +---rw path-srlgs-name* [usage]
                +---rw usage identityref
                +---rw names* string
        +---rw disjointness?
            te-path-disjointness

```

```

+---rw explicit-route-objects-always
+---rw route-object-exclude-always* [index]
+---rw index                                uint32
+---rw (type)?
+---:(numbered-node-hop)
+---rw numbered-node-hop
+---rw node-id          te-node-id
+---rw hop-type?        te-hop-type
+---:(numbered-link-hop)
+---rw numbered-link-hop
+---rw link-tp-id        te-tp-id
+---rw hop-type?        te-hop-type
+---rw direction?
+---rw                      te-link-direction
+---:(unnumbered-link-hop)
+---rw unnumbered-link-hop
+---rw link-tp-id        te-tp-id
+---rw node-id          te-node-id
+---rw hop-type?        te-hop-type
+---rw direction?
+---rw                      te-link-direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number          inet:as-number
+---rw hop-type?          te-hop-type
+---:(label)
+---rw label-hop
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw                      rt-types:generalized
- label
+---rw direction?
+---rw                      te-label-direction
+---rw route-object-include-exclude* [index]
+---rw explicit-route-usage?
+---rw identityref
+---rw index                                uint32
+---rw (type)?
+---:(numbered-node-hop)
+---rw numbered-node-hop
+---rw node-id          te-node-id
+---rw hop-type?        te-hop-type
+---:(numbered-link-hop)
+---rw numbered-link-hop
+---rw link-tp-id        te-tp-id
+---rw hop-type?        te-hop-type

```

				<pre> +---rw direction? te-link-direction +---:(unnumbered-link-hop) +---rw unnumbered-link-hop +---rw link-tp-id te-tp-id +---rw node-id te-node-id +---rw hop-type? te-hop-type +---rw direction? te-link-direction +---:(as-number) +---rw as-number-hop +---rw as-number inet:as-number +---rw hop-type? te-hop-type +---:(label) +---rw label-hop +---rw te-label +---rw (technology)? +---:(generic) +---rw generic? rt-types:generalized </pre>
-label				<pre> +---rw direction? te-label-direction +---:(srlg) +---rw srlg +---rw srlg? uint32 +---rw path-in-segment! +---rw label-restrictions +---rw label-restriction* [index] +---rw restriction? enumeration +---rw index uint32 +---rw label-start +---rw te-label +---rw (technology)? +---:(generic) +---rw generic? rt-types:generalized-la </pre>
bel				<pre> +---rw direction? te-label-direction +---rw label-end +---rw te-label +---rw (technology)? +---:(generic) +---rw generic? rt-types:generalized-la </pre>
bel				<pre> +---rw direction? </pre>

					<pre> te-label-direction +---rw label-step +---rw (technology)? +---:(generic) +---rw generic? int32 +---rw range-bitmap? yang:hex-string +---rw path-out-segment! +---rw label-restrictions +---rw label-restriction* [index] +---rw restriction? enumeration +---rw index uint32 +---rw label-start +---rw te-label +---rw (technology)? +---:(generic) +---rw generic? rt-types:generalized-la </pre>
bel					
					<pre> +---rw direction? te-label-direction +---rw label-end +---rw te-label +---rw (technology)? +---:(generic) +---rw generic? rt-types:generalized-la </pre>
bel					
					<pre> +---rw direction? te-label-direction +---rw label-step +---rw (technology)? +---:(generic) +---rw generic? int32 +---rw range-bitmap? yang:hex-string +---ro computed-paths-properties +---ro computed-path-properties* [k-index] +---ro k-index uint8 +---ro path-properties +---ro path-metric* [metric-type] +---ro metric-type identityref +---ro accumulative-value? uint64 +---ro path-affinities-values +---ro path-affinities-value* [usage] +---ro usage identityref +---ro value? admin-groups +---ro path-affinity-names +---ro path-affinity-name* [usage] </pre>

```

+---ro usage          identityref
+---ro affinity-name* [name]
+---ro name           string
+---ro path-srlgs-lists
+---ro path-srlgs-list* [usage]
+---ro usage          identityref
+---ro values*        srlg
+---ro path-srlgs-names
+---ro path-srlgs-name* [usage]
+---ro usage          identityref
+---ro names*         string
+---ro path-route-objects
+---ro path-route-object* [index]
+---ro index
+---ro (type)?
+---:(numbered-node-hop)
+---ro numbered-node-hop
+---ro node-id
+---ro hop-type?
+---ro te-hop-type
+---:(numbered-link-hop)
+---ro numbered-link-hop
+---ro link-tp-id
+---ro hop-type?
+---ro te-hop-type
+---ro direction?
+---ro te-link-direction
+---:(unnumbered-link-hop)
+---ro unnumbered-link-hop
+---ro link-tp-id
+---ro node-id
+---ro hop-type?
+---ro te-hop-type
+---ro direction?
+---ro te-link-direction
+---:(as-number)
+---ro as-number-hop
+---ro as-number
+---ro hop-type?
+---ro te-hop-type
+---:(label)
+---ro label-hop

```

```

+--ro te-label
+--ro (technology)?
+--:(generic)
+--ro generic?
rt-types:ge

neralized-label

+--ro direction?
te-label-directio

n

+--ro te-bandwidth
+--ro (technology)?
+--:(generic)
+--ro generic? te-bandwidth
+--ro disjointness-type?
te-types:te-path-disjointness
+--ro computed-path-error-infos
+--ro computed-path-error-info* []
+--ro error-description? string
+--ro error-timestamp?
| yang:date-and-time
+--ro error-reason? identityref
+--ro lsp-provisioning-error-infos
+--ro lsp-provisioning-error-info* []
+--ro error-description? string
+--ro error-timestamp?
| yang:date-and-time
+--ro error-node-id?
| te-types:te-node-id
+--ro error-link-id?
| te-types:te-tp-id
+--ro lsp-id? uint16
+--ro lsps
+--ro lsp* [node lsp-id]
+--ro tunnel-name?
| -> /te/lsps/lsp/tunnel-name
+--ro node -> /te/lsps/lsp/node
+--ro lsp-id -> /te/lsps/lsp/lsp-id
+--rw candidate-secondary-reverse-paths
+--rw candidate-secondary-reverse-path*
| [secondary-path]
+--rw secondary-path leafref
+--rw candidate-secondary-paths
+--rw candidate-secondary-path* [secondary-path]
+--rw secondary-path leafref
+--ro active? boolean
+--rw secondary-paths
+--rw secondary-path* [name]
+--rw name string

```

```

+--rw path-computation-method?          identityref
+--rw path-computation-server
|   +--rw id?      te-gen-node-id
|   +--rw type?    enumeration
+--rw compute-only?                      empty
+--rw use-path-computation?              boolean
+--rw lockdown?                          empty
+--ro path-scope?                        identityref
+--rw preference?                        uint8
+--rw association-objects
|   +--rw association-object* [association-key]
|   |   +--rw association-key    string
|   |   +--rw type?             identityref
|   |   +--rw id?               uint16
|   |   +--rw source
|   |   |   +--rw id?      te-gen-node-id
|   |   |   +--rw type?    enumeration
|   +--rw association-object-extended*
|   |   [association-key]
|   |   +--rw association-key    string
|   |   +--rw type?             identityref
|   |   +--rw id?               uint16
|   |   +--rw source
|   |   |   +--rw id?      te-gen-node-id
|   |   |   +--rw type?    enumeration
|   +--rw global-source?          uint32
|   +--rw extended-id?            yang:hex-string
+--rw optimizations
|   +--rw (algorithm)?
|   |   +--:(metric) {path-optimization-metric}?
|   |   |   +--rw optimization-metric* [metric-type]
|   |   |   |   +--rw metric-type
|   |   |   |   |   identityref
|   |   |   |   +--rw weight?
|   |   |   |   |   uint8
|   |   |   +--rw explicit-route-exclude-objects
|   |   |   |   +--rw route-object-exclude-object*
|   |   |   |   |   [index]
|   |   |   |   |   +--rw index
|   |   |   |   |   |   uint32
|   |   |   |   +--rw (type)?
|   |   |   |   |   +--:(numbered-node-hop)
|   |   |   |   |   |   +--rw numbered-node-hop
|   |   |   |   |   |   |   +--rw node-id
|   |   |   |   |   |   |   |   te-node-id
|   |   |   |   |   |   |   +--rw hop-type?
|   |   |   |   |   |   |   |   te-hop-type
|   |   |   |   +--:(numbered-link-hop)

```

```

+--rw numbered-link-hop
+--rw link-tp-id
|   te-tp-id
+--rw hop-type?
|   te-hop-type
+--rw direction?
|   te-link-direction
+--:(unnumbered-link-hop)
+--rw unnumbered-link-hop
+--rw link-tp-id
|   te-tp-id
+--rw node-id
|   te-node-id
+--rw hop-type?
|   te-hop-type
+--rw direction?
|   te-link-direction
+--:(as-number)
+--rw as-number-hop
+--rw as-number
|   inet:as-number
+--rw hop-type?
|   te-hop-type
+--:(label)
+--rw label-hop
+--rw te-label
|   +--rw (technology)?
|   |   +--:(generic)
|   |   +--rw generic?
|   |   rt-types:ge
neralized-label
n
+--rw direction?
|   te-label-directio
+--:(srlg)
+--rw srlg
|   +--rw srlg?   uint32
+--rw explicit-route-include-objects
+--rw route-object-include-object*
|   [index]
+--rw index
|   uint32
+--rw (type)?
+--:(numbered-node-hop)
+--rw numbered-node-hop
|   +--rw node-id
|   |   te-node-id
+--rw hop-type?

```


						te-hop-type
					+	---:(numbered-link-hop)
						+---rw numbered-link-hop
						+---rw link-tp-id
						te-tp-id
						+---rw hop-type?
						te-hop-type
						+---rw direction?
						te-link-direction
					+	---:(unnumbered-link-hop)
						+---rw unnumbered-link-hop
						+---rw link-tp-id
						te-tp-id
						+---rw node-id
						te-node-id
						+---rw hop-type?
						te-hop-type
						+---rw direction?
						te-link-direction
					+	---:(as-number)
						+---rw as-number-hop
						+---rw as-number
						inet:as-number
						+---rw hop-type?
						te-hop-type
					+	---:(label)
						+---rw label-hop
						+---rw te-label
						+---rw (technology)?
						+---:(generic)
						+---rw generic?
						rt-types:ge
neralized-label						
						+---rw direction?
						te-label-directio
n						
						+---rw tiebreakers
						+---rw tiebreaker* [tiebreaker-type]
						+---rw tiebreaker-type identityref
					+	---:(objective-function)
						{path-optimization-objective-function}?
						+---rw objective-function
						+---rw objective-function-type?
						identityref
					+	---rw named-path-constraint? leafref
						{te-types:named-path-constraints}?
					+	---rw te-bandwidth
						+---rw (technology)?

```

    +---:(generic)
      +---rw generic?    te-bandwidth
+---rw link-protection?          identityref
+---rw setup-priority?          uint8
+---rw hold-priority?           uint8
+---rw signaling-type?          identityref
+---rw path-metric-bounds
  +---rw path-metric-bound* [metric-type]
  +---rw metric-type        identityref
  +---rw upper-bound?      uint64
+---rw path-affinities-values
  +---rw path-affinities-value* [usage]
  +---rw usage                identityref
  +---rw value?              admin-groups
+---rw path-affinity-names
  +---rw path-affinity-name* [usage]
  +---rw usage                identityref
  +---rw affinity-name* [name]
  +---rw name                string
+---rw path-srlgs-lists
  +---rw path-srlgs-list* [usage]
  +---rw usage              identityref
  +---rw values*           srlg
+---rw path-srlgs-names
  +---rw path-srlgs-name* [usage]
  +---rw usage            identityref
  +---rw names*          string
+---rw disjointness?
  +---rw te-path-disjointness
+---rw explicit-route-objects-always
  +---rw route-object-exclude-always* [index]
  +---rw index                        uint32
  +---rw (type)?
    +---:(numbered-node-hop)
      +---rw numbered-node-hop
      +---rw node-id          te-node-id
      +---rw hop-type?       te-hop-type
    +---:(numbered-link-hop)
      +---rw numbered-link-hop
      +---rw link-tp-id      te-tp-id
      +---rw hop-type?       te-hop-type
      +---rw direction?     te-link-direction
    +---:(unnumbered-link-hop)
      +---rw unnumbered-link-hop
      +---rw link-tp-id      te-tp-id
      +---rw node-id        te-node-id
      +---rw hop-type?       te-hop-type
      +---rw direction?     te-link-direction

```

				<pre> +--:(as-number) +--rw as-number-hop +--rw as-number inet:as-number +--rw hop-type? te-hop-type +--:(label) +--rw label-hop +--rw te-label +--rw (technology)? +--:(generic) +--rw generic? rt-types:generalized-la </pre>
bel				<pre> +--rw direction? te-label-direction +--rw route-object-include-exclude* [index] +--rw explicit-route-usage? identityref +--rw index uint32 +--rw (type)? +--:(numbered-node-hop) +--rw numbered-node-hop +--rw node-id te-node-id +--rw hop-type? te-hop-type +--:(numbered-link-hop) +--rw numbered-link-hop +--rw link-tp-id te-tp-id +--rw hop-type? te-hop-type +--rw direction? te-link-direction +--:(unnumbered-link-hop) +--rw unnumbered-link-hop +--rw link-tp-id te-tp-id +--rw node-id te-node-id +--rw hop-type? te-hop-type +--rw direction? te-link-direction +--:(as-number) +--rw as-number-hop +--rw as-number inet:as-number +--rw hop-type? te-hop-type +--:(label) +--rw label-hop +--rw te-label +--rw (technology)? +--:(generic) +--rw generic? rt-types:generalized-la </pre>
bel				<pre> +--rw direction? te-label-direction +--:(srlg) </pre>

```

        +---rw srlg
            +---rw srlg?   uint32
+---rw path-in-segment!
    +---rw label-restrictions
        +---rw label-restriction* [index]
            +---rw restriction?   enumeration
            +---rw index          uint32
            +---rw label-start
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?
                        te-label-direction
            +---rw label-end
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?
                        te-label-direction
            +---rw label-step
                +---rw (technology)?
                    +---:(generic)
                        +---rw generic?   int32
            +---rw range-bitmap?   yang:hex-string
+---rw path-out-segment!
    +---rw label-restrictions
        +---rw label-restriction* [index]
            +---rw restriction?   enumeration
            +---rw index          uint32
            +---rw label-start
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?
                        te-label-direction
            +---rw label-end
                +---rw te-label
                    +---rw (technology)?
                        +---:(generic)
                            +---rw generic?
                                rt-types:generalized-label
                    +---rw direction?

```

```

|                                     te-label-direction
|   +---rw label-step
|   |   +---rw (technology)?
|   |   |   +---:(generic)
|   |   |   +---rw generic?    int32
|   +---rw range-bitmap?    yang:hex-string
+---rw protection
|   +---rw enable?                                boolean
|   +---rw protection-type?                        identityref
|   +---rw protection-reversion-disable?          boolean
|   +---rw hold-off-time?                          uint32
|   +---rw wait-to-revert?                        uint16
|   +---rw aps-signal-id?                          uint8
+---rw restoration
|   +---rw enable?                                boolean
|   +---rw restoration-type?
|   |   identityref
|   +---rw restoration-scheme?
|   |   identityref
|   +---rw restoration-reversion-disable?          boolean
|   +---rw hold-off-time?                          uint32
|   +---rw wait-to-restore?                        uint16
|   +---rw wait-to-revert?                        uint16
+---ro computed-paths-properties
|   +---ro computed-path-properties* [k-index]
|   |   +---ro k-index                          uint8
|   |   +---ro path-properties
|   |   |   +---ro path-metric* [metric-type]
|   |   |   |   +---ro metric-type                identityref
|   |   |   |   +---ro accumulative-value?        uint64
|   |   +---ro path-affinities-values
|   |   |   +---ro path-affinities-value* [usage]
|   |   |   |   +---ro usage                      identityref
|   |   |   |   +---ro value?                    admin-groups
|   |   +---ro path-affinity-names
|   |   |   +---ro path-affinity-name* [usage]
|   |   |   |   +---ro usage                      identityref
|   |   |   |   +---ro affinity-name* [name]
|   |   |   |   |   +---ro name                    string
|   |   +---ro path-srlgs-lists
|   |   |   +---ro path-srlgs-list* [usage]
|   |   |   |   +---ro usage                      identityref
|   |   |   |   +---ro values*                    srlg
|   |   +---ro path-srlgs-names
|   |   |   +---ro path-srlgs-name* [usage]
|   |   |   |   +---ro usage                      identityref
|   |   |   |   +---ro names*                    string
|   +---ro path-route-objects

```

				+--ro path-route-object* [index]
				+--ro index
				uint32
				+--ro (type)?
				+--:(numbered-node-hop)
				+--ro numbered-node-hop
				+--ro node-id te-node-id
				+--ro hop-type?
				te-hop-type
				+--:(numbered-link-hop)
				+--ro numbered-link-hop
				+--ro link-tp-id te-tp-id
				+--ro hop-type?
				te-hop-type
				+--ro direction?
				te-link-direction
				+--:(unnumbered-link-hop)
				+--ro unnumbered-link-hop
				+--ro link-tp-id te-tp-id
				+--ro node-id
				te-node-id
				+--ro hop-type?
				te-hop-type
				+--ro direction?
				te-link-direction
				+--:(as-number)
				+--ro as-number-hop
				+--ro as-number
				inet:as-number
				+--ro hop-type?
				te-hop-type
				+--:(label)
				+--ro label-hop
				+--ro te-label
				+--ro (technology)?
				+--:(generic)
				+--ro generic?
				rt-types:gener
				+--ro direction?
				te-label-direction
				+--ro te-bandwidth
				+--ro (technology)?
				+--:(generic)
				+--ro generic? te-bandwidth
				+--ro disjointness-type?
				te-types:te-path-disjointness
				+--ro computed-path-error-infos

alized-label

```

    +---ro computed-path-error-info* []
    |   +---ro error-description?    string
    |   +---ro error-timestamp?      yang:date-and-time
    |   +---ro error-reason?         identityref
+---ro lsp-provisioning-error-infos
|   +---ro lsp-provisioning-error-info* []
|   |   +---ro error-description?    string
|   |   +---ro error-timestamp?      yang:date-and-time
|   |   +---ro error-node-id?        te-types:te-node-id
|   |   +---ro error-link-id?        te-types:te-tp-id
|   |   +---ro lsp-id?               uint16
+---ro lsps
|   +---ro lsp* [node lsp-id]
|   |   +---ro tunnel-name?
|   |   |       -> /te/lsps/lsp/tunnel-name
|   |   +---ro node                  -> /te/lsps/lsp/node
|   |   +---ro lsp-id                -> /te/lsps/lsp/lsp-id
+---rw secondary-reverse-paths
|   +---rw secondary-reverse-path* [name]
|   |   +---rw name                  string
|   |   +---rw path-computation-method? identityref
|   |   +---rw path-computation-server
|   |   |   +---rw id?               te-gen-node-id
|   |   |   +---rw type?             enumeration
|   |   +---rw compute-only?         empty
|   |   +---rw use-path-computation? boolean
|   |   +---rw lockdown?             empty
|   |   +---ro path-scope?           identityref
|   |   +---rw preference?           uint8
+---rw association-objects
|   +---rw association-object* [association-key]
|   |   +---rw association-key        string
|   |   +---rw type?                 identityref
|   |   +---rw id?                   uint16
|   |   +---rw source
|   |   |   +---rw id?               te-gen-node-id
|   |   |   +---rw type?             enumeration
+---rw association-object-extended*
|   [association-key]
|   +---rw association-key            string
|   +---rw type?                     identityref
|   +---rw id?                       uint16
|   +---rw source
|   |   +---rw id?                   te-gen-node-id
|   |   +---rw type?                 enumeration
+---rw global-source?                uint32
+---rw extended-id?                  yang:hex-string
+---rw optimizations

```

```

+--rw (algorithm)?
+--:(metric) {path-optimization-metric}?
+--rw optimization-metric* [metric-type]
+--rw metric-type
|   identityref
+--rw weight?
|   uint8
+--rw explicit-route-exclude-objects
+--rw route-object-exclude-object*
|   [index]
+--rw index
|   uint32
+--rw (type)?
+--:(numbered-node-hop)
+--rw numbered-node-hop
+--rw node-id
|   te-node-id
+--rw hop-type?
|   te-hop-type
+--:(numbered-link-hop)
+--rw numbered-link-hop
+--rw link-tp-id
|   te-tp-id
+--rw hop-type?
|   te-hop-type
+--rw direction?
|   te-link-direction
+--:(unnumbered-link-hop)
+--rw unnumbered-link-hop
+--rw link-tp-id
|   te-tp-id
+--rw node-id
|   te-node-id
+--rw hop-type?
|   te-hop-type
+--rw direction?
|   te-link-direction
+--:(as-number)
+--rw as-number-hop
+--rw as-number
|   inet:as-number
+--rw hop-type?
|   te-hop-type
+--:(label)
+--rw label-hop
+--rw te-label
+--rw (technology)?
|   +--:(generic)

```



```

+---rw generic?
      rt-types:generic
n
+---rw direction?
      te-label-direction
+---:(srlg)
  +---rw srlg
  +---rw srlg?   uint32
+---rw explicit-route-include-objects
  +---rw route-object-include-object*
    [index]
  +---rw index
    |   uint32
  +---rw (type)?
    +---:(numbered-node-hop)
      +---rw numbered-node-hop
      +---rw node-id
      |   te-node-id
      +---rw hop-type?
      |   te-hop-type
    +---:(numbered-link-hop)
      +---rw numbered-link-hop
      +---rw link-tp-id
      |   te-tp-id
      +---rw hop-type?
      |   te-hop-type
      +---rw direction?
      |   te-link-direction
    +---:(unnumbered-link-hop)
      +---rw unnumbered-link-hop
      +---rw link-tp-id
      |   te-tp-id
      +---rw node-id
      |   te-node-id
      +---rw hop-type?
      |   te-hop-type
      +---rw direction?
      |   te-link-direction
    +---:(as-number)
      +---rw as-number-hop
      +---rw as-number
      |   inet:as-number
      +---rw hop-type?
      |   te-hop-type
    +---:(label)
      +---rw label-hop
      +---rw te-label

```

```

+---rw (technology)?
+---:(generic)
+---rw generic?
rt-types:generic
n
+---rw direction?
te-label-direction
+---rw tiebreakers
+---rw tiebreaker* [tiebreaker-type]
+---rw tiebreaker-type identityref
+---:(objective-function)
{path-optimization-objective-function}?
+---rw objective-function
+---rw objective-function-type?
identityref
+---rw named-path-constraint? leafref
{te-types:named-path-constraints}?
+---rw te-bandwidth
+---rw (technology)?
+---:(generic)
+---rw generic? te-bandwidth
+---rw link-protection? identityref
+---rw setup-priority? uint8
+---rw hold-priority? uint8
+---rw signaling-type? identityref
+---rw path-metric-bounds
+---rw path-metric-bound* [metric-type]
+---rw metric-type identityref
+---rw upper-bound? uint64
+---rw path-affinities-values
+---rw path-affinities-value* [usage]
+---rw usage identityref
+---rw value? admin-groups
+---rw path-affinity-names
+---rw path-affinity-name* [usage]
+---rw usage identityref
+---rw affinity-name* [name]
+---rw name string
+---rw path-srlgs-lists
+---rw path-srlgs-list* [usage]
+---rw usage identityref
+---rw values* srlg
+---rw path-srlgs-names
+---rw path-srlgs-name* [usage]
+---rw usage identityref
+---rw names* string
+---rw disjointness?

```

				te-path-disjointness
			+--rw	explicit-route-objects-always
			+--rw	route-object-exclude-always* [index]
			+--rw	index uint32
			+--rw	(type)?
			+--:	(numbered-node-hop)
			+--rw	numbered-node-hop
			+--rw	node-id te-node-id
			+--rw	hop-type? te-hop-type
			+--:	(numbered-link-hop)
			+--rw	numbered-link-hop
			+--rw	link-tp-id te-tp-id
			+--rw	hop-type? te-hop-type
			+--rw	direction? te-link-direction
			+--:	(unnumbered-link-hop)
			+--rw	unnumbered-link-hop
			+--rw	link-tp-id te-tp-id
			+--rw	node-id te-node-id
			+--rw	hop-type? te-hop-type
			+--rw	direction? te-link-direction
			+--:	(as-number)
			+--rw	as-number-hop
			+--rw	as-number inet:as-number
			+--rw	hop-type? te-hop-type
			+--:	(label)
			+--rw	label-hop
			+--rw	te-label
			+--rw	(technology)?
			+--:	(generic)
			+--rw	generic?
				rt-types:generalized-la
			+--rw	direction?
				te-label-direction
			+--rw	route-object-include-exclude* [index]
			+--rw	explicit-route-usage? identityref
			+--rw	index uint32
			+--rw	(type)?
			+--:	(numbered-node-hop)
			+--rw	numbered-node-hop
			+--rw	node-id te-node-id
			+--rw	hop-type? te-hop-type
			+--:	(numbered-link-hop)
			+--rw	numbered-link-hop
			+--rw	link-tp-id te-tp-id
			+--rw	hop-type? te-hop-type
			+--rw	direction? te-link-direction
			+--:	(unnumbered-link-hop)

```

+--rw unnumbered-link-hop
+--rw link-tp-id      te-tp-id
+--rw node-id         te-node-id
+--rw hop-type?      te-hop-type
+--rw direction?     te-link-direction
+--:(as-number)
+--rw as-number-hop
+--rw as-number      inet:as-number
+--rw hop-type?     te-hop-type
+--:(label)
+--rw label-hop
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-types:generalized-label
+--rw direction?
te-label-direction
+--:(srlg)
+--rw srlg
+--rw srlg?   uint32
+--rw path-in-segment!
+--rw label-restrictions
+--rw label-restriction* [index]
+--rw restriction?   enumeration
+--rw index          uint32
+--rw label-start
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-types:generalized-label
+--rw direction?
te-label-direction
+--rw label-end
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-types:generalized-label
+--rw direction?
te-label-direction
+--rw label-step
+--rw (technology)?
+--:(generic)
+--rw generic?   int32
+--rw range-bitmap?   yang:hex-string

```

```

+--rw path-out-segment!
  +--rw label-restrictions
    +--rw label-restriction* [index]
      +--rw restriction?      enumeration
      +--rw index             uint32
      +--rw label-start
        +--rw te-label
          +--rw (technology)?
          |   +--:(generic)
          |   +--rw generic?
          |       rt-types:generalized-label
          +--rw direction?
          |       te-label-direction
          +--rw label-end
            +--rw te-label
              +--rw (technology)?
              |   +--:(generic)
              |   +--rw generic?
              |       rt-types:generalized-label
              +--rw direction?
              |       te-label-direction
              +--rw label-step
                +--rw (technology)?
                |   +--:(generic)
                |   +--rw generic?      int32
                +--rw range-bitmap?     yang:hex-string
      +--rw protection
        +--rw enable?                  boolean
        +--rw protection-type?         identityref
        +--rw protection-reversion-disable? boolean
        +--rw hold-off-time?           uint32
        +--rw wait-to-revert?          uint16
        +--rw aps-signal-id?           uint8
      +--rw restoration
        +--rw enable?                  boolean
        +--rw restoration-type?
        |   identityref
        +--rw restoration-scheme?
        |   identityref
        +--rw restoration-reversion-disable? boolean
        +--rw hold-off-time?           uint32
        +--rw wait-to-restore?         uint16
        +--rw wait-to-revert?          uint16
+--ro computed-paths-properties
  +--ro computed-path-properties* [k-index]
    +--ro k-index                     uint8
    +--ro path-properties
      +--ro path-metric* [metric-type]

```

```

|   +---ro metric-type          identityref
|   +---ro accumulative-value?  uint64
+---ro path-affinities-values
|   +---ro path-affinities-value* [usage]
|   +---ro usage                identityref
|   +---ro value?               admin-groups
+---ro path-affinity-names
|   +---ro path-affinity-name* [usage]
|   +---ro usage                identityref
|   +---ro affinity-name* [name]
|   +---ro name                 string
+---ro path-srlgs-lists
|   +---ro path-srlgs-list* [usage]
|   +---ro usage                identityref
|   +---ro values*             srlg
+---ro path-srlgs-names
|   +---ro path-srlgs-name* [usage]
|   +---ro usage                identityref
|   +---ro names*              string
+---ro path-route-objects
|   +---ro path-route-object* [index]
|   +---ro index
|   |   uint32
|   +---ro (type)?
|   |   +---:(numbered-node-hop)
|   |   |   +---ro numbered-node-hop
|   |   |   |   +---ro node-id      te-node-id
|   |   |   |   +---ro hop-type?
|   |   |   |   |   te-hop-type
|   |   |   +---:(numbered-link-hop)
|   |   |   |   +---ro numbered-link-hop
|   |   |   |   |   +---ro link-tp-id  te-tp-id
|   |   |   |   |   +---ro hop-type?
|   |   |   |   |   |   te-hop-type
|   |   |   |   |   +---ro direction?
|   |   |   |   |   |   te-link-direction
|   |   |   +---:(unnumbered-link-hop)
|   |   |   |   +---ro unnumbered-link-hop
|   |   |   |   |   +---ro link-tp-id  te-tp-id
|   |   |   |   |   +---ro node-id
|   |   |   |   |   |   te-node-id
|   |   |   |   |   +---ro hop-type?
|   |   |   |   |   |   te-hop-type
|   |   |   |   |   +---ro direction?
|   |   |   |   |   |   te-link-direction
|   |   +---:(as-number)
|   |   |   +---ro as-number-hop
|   |   |   +---ro as-number

```

```

| | | | | | | inet:as-number
| | | | | | | +---ro hop-type?
| | | | | | | | te-hop-type
| | | | | | | +---:(label)
| | | | | | | | +---ro label-hop
| | | | | | | | | +---ro te-label
| | | | | | | | | | +---ro (technology)?
| | | | | | | | | | | +---:(generic)
| | | | | | | | | | | | +---ro generic?
| | | | | | | | | | | | rt-types:gener
alized-label
| | | | | | | | +---ro direction?
| | | | | | | | | te-label-direction
| | | | | | | +---ro te-bandwidth
| | | | | | | | +---ro (technology)?
| | | | | | | | | +---:(generic)
| | | | | | | | | +---ro generic? te-bandwidth
| | | | | | | +---ro disjointness-type?
| | | | | | | | te-types:te-path-disjointness
+---ro computed-path-error-infos
| +---ro computed-path-error-info* []
| | +---ro error-description? string
| | +---ro error-timestamp? yang:date-and-time
| | +---ro error-reason? identityref
+---ro lsp-provisioning-error-infos
| +---ro lsp-provisioning-error-info* []
| | +---ro error-description? string
| | +---ro error-timestamp? yang:date-and-time
| | +---ro error-node-id? te-types:te-node-id
| | +---ro error-link-id? te-types:te-tp-id
| | +---ro lsp-id? uint16
+---ro lsps
| +---ro lsp* [node lsp-id]
| | +---ro tunnel-name?
| | | -> /te/lsp/lsps/tunnel-name
| | +---ro node -> /te/lsp/lsps/node
| | +---ro lsp-id -> /te/lsp/lsps/lsp-id
+---x tunnel-action
| +---w input
| | +---w action-type? identityref
+---ro output
| +---ro action-result? identityref
+---x protection-external-commands
| +---w input
| | +---w protection-external-command?
| | | identityref
| | +---w protection-group-ingress-node-id?
| | | te-types:te-node-id

```

```

|         +---w protection-group-egress-node-id?
|         |         te-types:te-node-id
|         +---w path-ref?                                path-ref
|         +---w traffic-type?
|         |         enumeration
|         +---w extra-traffic-tunnel-ref?                tunnel-ref
+---ro lsp
+---ro lsp* [tunnel-name lsp-id node]
+---ro tunnel-name                                string
+---ro lsp-id                                    uint16
+---ro node
|         te-types:te-node-id
+---ro source?
|         te-types:te-node-id
+---ro destination?
|         te-types:te-node-id
+---ro tunnel-id?                                uint16
+---ro extended-tunnel-id?                        yang:dotted-quad
+---ro operational-state?                        identityref
+---ro signaling-type?                          identityref
+---ro origin-type?                            enumeration
+---ro lsp-resource-status?                     enumeration
+---ro lockout-of-normal?                      boolean
+---ro freeze?                                boolean
+---ro lsp-protection-role?                    enumeration
+---ro lsp-protection-state?                  identityref
+---ro protection-group-ingress-node-id?
|         te-types:te-node-id
+---ro protection-group-egress-node-id?
|         te-types:te-node-id
+---ro lsp-record-route-information
+---ro lsp-record-route-information* [index]
+---ro index                                    uint32
+---ro (type)?
+---:(numbered-node-hop)
|         +---ro numbered-node-hop
|         |         +---ro node-id      te-node-id
|         |         +---ro flags*      path-attribute-flags
+---:(numbered-link-hop)
|         +---ro numbered-link-hop
|         |         +---ro link-tp-id   te-tp-id
|         |         +---ro flags*      path-attribute-flags
+---:(unnumbered-link-hop)
|         +---ro unnumbered-link-hop
|         |         +---ro link-tp-id   te-tp-id
|         |         +---ro node-id?    te-node-id
|         |         +---ro flags*      path-attribute-flags
+---:(label)

```

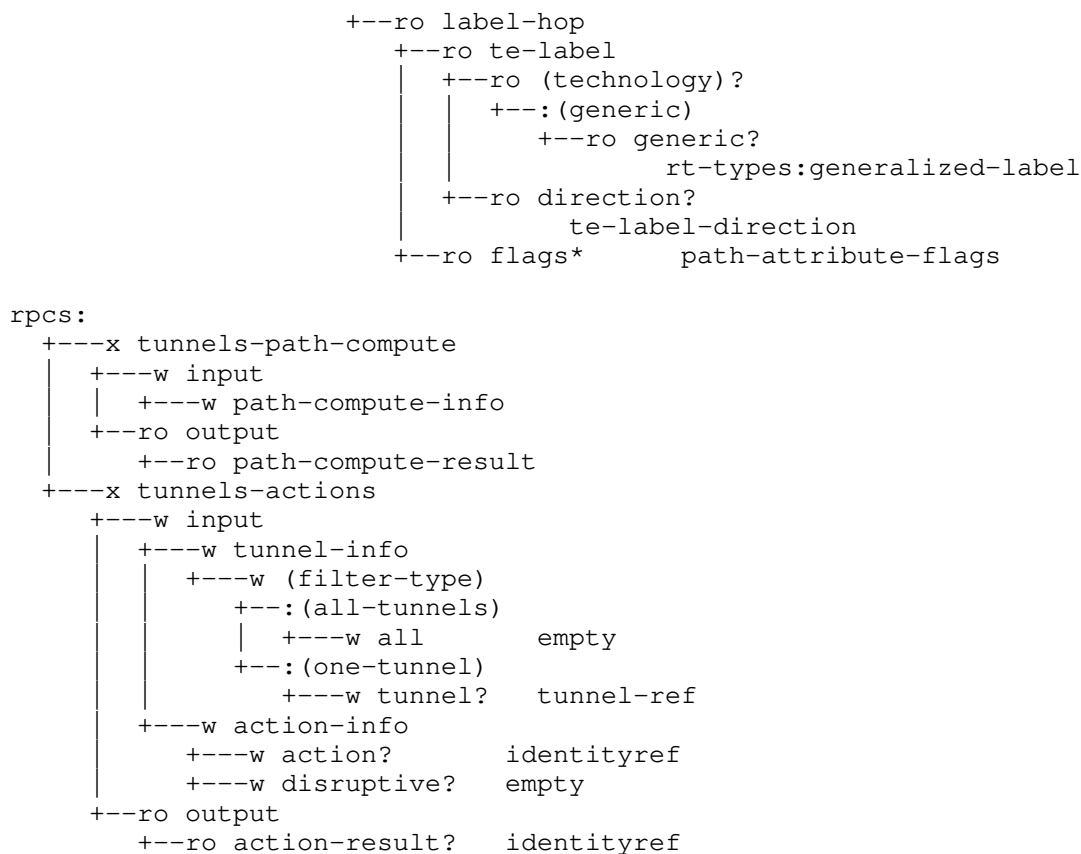



Figure 8: TE Tunnel generic model YANG tree diagram

5.3. YANG Module

The generic TE YANG module 'ietf-te' imports the following modules:

- ```
* ietf-yang-types and ietf-inet-types defined in [RFC6991]
* ietf-te-types defined in [RFC8776]
```

This module references the following documents: [RFC6991], [RFC4875], [RFC7551], [RFC4206], [RFC4427], [RFC4872], [RFC3945], [RFC3209], [RFC6780], [RFC8800], and [RFC7308].

```
<CODE BEGINS> file "ietf-te@2021-10-22.yang"
module ietf-te {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te";

 /* Replace with IANA when assigned */

 prefix te;

 /* Import TE generic types */

 import ietf-te-types {
 prefix te-types;
 reference
 "RFC8776: Common YANG Data Types for Traffic Engineering.";
 }
 import ietf-inet-types {
 prefix inet;
 reference
 "RFC6991: Common YANG Data Types.";
 }
 import ietf-yang-types {
 prefix yang;
 reference
 "RFC6991: Common YANG Data Types.";
 }
}

organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group.";
contact
 "WG Web: <http://tools.ietf.org/wg/teas/>
 WG List: <mailto:teas@ietf.org>

 Editor: Tarek Saad
 <mailto:tsaad@juniper.net>

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 <mailto:rgandhi@cisco.com>

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 <mailto:vbeeram@juniper.net>

 Editor: Himanshu Shah
 <mailto:hshah@ciena.com>

 Editor: Xufeng Liu
 <mailto:xufeng.liu.ietf@gmail.com>
```

```
Editor: Igor Bryskin
 <mailto:i_bryskin@yahoo.com>;
description
 "YANG data module for TE configuration, state, and RPCs.
 The model fully conforms to the Network Management
 Datastore Architecture (NMDA).

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 identified as authors of the code. All rights reserved.

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 set forth in Section 4.c of the IETF Trust's Legal Provisions
 Relating to IETF Documents
 (https://trustee.ietf.org/license-info).
 This version of this YANG module is part of RFC XXXX; see
 the RFC itself for full legal notices.";

// RFC Ed.: replace XXXX with actual RFC number and remove this
// note.
// RFC Ed.: update the date below with the date of RFC publication
// and remove this note.

revision 2021-10-22 {
 description
 "Latest update to TE generic YANG module.";
 reference
 "RFCXXXX: A YANG Data Model for Traffic Engineering Tunnels
 and Interfaces.";
}

identity path-computation-error-reason {
 description
 "Base identity for path computation error reasons.";
}

identity path-computation-error-no-topology {
 base path-computation-error-reason;
 description
 "Path computation has failed because there is no topology
 with the provided topology-identifier.";
}

identity path-computation-error-no-dependent-server {
 base path-computation-error-reason;
 description
 "Path computation has failed because one or more dependent
```

```
 path computation servers are unavailable.
 The dependent path computation server could be
 a Backward-Recursive Path Computation (BRPC) downstream
 PCE or a child PCE.";
 reference
 "RFC5441, RFC8685";
}

identity path-computation-error-pce-unavailable {
 base path-computation-error-reason;
 description
 "Path computation has failed because PCE is not available.";
 reference
 "RFC5440";
}

identity path-computation-error-no-inclusion-hop {
 base path-computation-error-reason;
 description
 "Path computation has failed because there is no
 node or link provided by one or more inclusion hops.";
 reference
 "RFC8685";
}

identity path-computation-error-destination-unknown-in-domain {
 base path-computation-error-reason;
 description
 "Path computation has failed because the destination node is
 unknown in indicated destination domain.";
 reference
 "RFC8685";
}

identity path-computation-error-no-resource {
 base path-computation-error-reason;
 description
 "Path computation has failed because there is no
 available resource in one or more domains.";
 reference
 "RFC8685";
}

identity path-computation-error-child-pce-unresponsive {
 base path-computation-error-reason;
 description
 "Path computation has failed because child PCE is not
 responsive.";
```

```
 reference
 "RFC8685";
 }

 identity path-computation-error-destination-domain-unknown {
 base path-computation-error-reason;
 description
 "Path computation has failed because the destination domain
 was unknown.";
 reference
 "RFC8685";
 }

 identity path-computation-error-p2mp {
 base path-computation-error-reason;
 description
 "Path computation has failed because of P2MP reachability
 problem.";
 reference
 "RFC8306";
 }

 identity path-computation-error-no-gco-migration {
 base path-computation-error-reason;
 description
 "Path computation has failed because of no Global Concurrent
 Optimization (GCO) migration path found.";
 reference
 "RFC5557";
 }

 identity path-computation-error-no-gco-solution {
 base path-computation-error-reason;
 description
 "Path computation has failed because of no GCO solution
 found.";
 reference
 "RFC5557";
 }

 identity path-computation-error-path-not-found {
 base path-computation-error-reason;
 description
 "Path computation no path found error reason.";
 reference
 "RFC5440";
 }
 }
```

```
identity path-computation-error-pks-expansion {
 base path-computation-error-reason;
 description
 "Path computation has failed because of Path-Key Subobject
 (PKS) expansion failure.";
 reference
 "RFC5520";
}

identity path-computation-error-brpc-chain-unavailable {
 base path-computation-error-reason;
 description
 "Path computation has failed because PCE BRPC chain
 unavailable.";
 reference
 "RFC5441";
}

identity path-computation-error-source-unknown {
 base path-computation-error-reason;
 description
 "Path computation has failed because source node is unknown.";
 reference
 "RFC5440";
}

identity path-computation-error-destination-unknown {
 base path-computation-error-reason;
 description
 "Path computation has failed because destination node is
 unknown.";
 reference
 "RFC5440";
}

identity path-computation-error-no-server {
 base path-computation-error-reason;
 description
 "Path computation has failed because path computation
 server is unavailable.";
 reference
 "RFC5440";
}

identity tunnel-actions-type {
 description
 "TE tunnel actions type.";
}
```

```
identity tunnel-action-reoptimize {
 base tunnel-actions-type;
 description
 "Reoptimize tunnel action type.";
}

identity tunnel-admin-auto {
 base te-types:tunnel-admin-state-type;
 description
 "Tunnel administrative auto state. The administrative status
 in state datastore transitions to 'tunnel-admin-up' when the
 tunnel used by the client layer, and to 'tunnel-admin-down'
 when it is not used by the client layer.";
}

identity association-type-diversity {
 base te-types:association-type;
 description
 "Association Type diversity used to associate LSPs whose paths
 are to be diverse from each other.";
 reference
 "RFC8800";
}

identity protocol-origin-type {
 description
 "Base identity for protocol origin type.";
}

identity protocol-origin-api {
 base protocol-origin-type;
 description
 "Protocol origin is via Application Programmable Interface
 (API).";
}

identity protocol-origin-pcep {
 base protocol-origin-type;
 description
 "Protocol origin is Path Computation Engine Protocol (PCEP).";
 reference "RFC5440";
}

identity protocol-origin-bgp {
 base protocol-origin-type;
 description
 "Protocol origin is Border Gateway Protocol (BGP).";
 reference "RFC5512";
}

typedef tunnel-ref {
```

```
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/te:name";
 }
 description
 "This type is used by data models that need to reference
 configured TE tunnel.";
 }

 typedef path-ref {
 type union {
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/"
 + "te:primary-paths/te:primary-path/te:name";
 }
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/"
 + "te:secondary-paths/te:secondary-path/te:name";
 }
 }
 description
 "This type is used by data models that need to reference
 configured primary or secondary path of a TE tunnel.";
 }

 typedef te-gen-node-id {
 type union {
 type te-types:te-node-id;
 type inet:ip-address;
 }
 description
 "Generic type that identifies a node in a TE topology.";
 }

 /**
 * TE tunnel generic groupings
 */

 grouping te-generic-node-id {
 description
 "A reusable grouping for a TE generic node identifier.";
 leaf id {
 type te-gen-node-id;
 description
 "The identifier of the node. Can be represented as IP
 address or dotted quad address.";
 }
 leaf type {
 type enumeration {
```



```
 enum ip {
 description
 "IP address representation of the node identifier.";
 }
 enum dotted-quad {
 description
 "Dotted quad address representation of the node
 identifier.";
 }
 }
 description
 "Type of node identifier representation.";
}

grouping primary-path {
 description
 "The tunnel primary path properties.";
 uses path-common-properties;
 uses path-preference;
 uses k-requested-paths;
 uses path-compute-info;
 uses path-state;
}

grouping primary-reverse-path {
 description
 "The tunnel primary reverse path properties.";
 reference
 "RFC7551";
 uses path-common-properties;
 uses path-compute-info;
 uses path-state;
}

grouping secondary-path {
 description
 "The tunnel secondary path properties.";
 uses path-common-properties;
 uses path-preference;
 uses path-compute-info;
 uses protection-restoration-properties;
 uses path-state;
}

grouping secondary-reverse-path {
 description
 "The tunnel secondary reverse path properties.";
```

```
 uses path-common-properties;
 uses path-preference;
 uses path-compute-info;
 uses protection-restoration-properties;
 uses path-state;
}

grouping path-common-properties {
 description
 "Common path attributes.";
 leaf name {
 type string;
 description
 "TE path name.";
 }
 leaf path-computation-method {
 type identityref {
 base te-types:path-computation-method;
 }
 default "te-types:path-locally-computed";
 description
 "The method used for computing the path, either
 locally computed, queried from a server or not
 computed at all (explicitly configured).";
 }
 container path-computation-server {
 when "derived-from-or-self(..path-computation-method, "
 + "'te-types:path-externally-queried') " {
 description
 "The path-computation server when the path is
 externally queried.";
 }
 uses te-generic-node-id;
 description
 "Address of the external path computation
 server.";
 }
 leaf compute-only {
 type empty;
 description
 "When set, the path is computed and updated whenever
 the topology is updated. No resources are committed
 or reserved in the network.";
 }
 leaf use-path-computation {
 when "derived-from-or-self(..path-computation-method, "
 + "'te-types:path-locally-computed') " {
 type boolean;
 }
 }
}
```

```
 default "true";
 description
 "When 'true' indicates the path is dynamically computed
 and/or validated against the Traffic-Engineering Database
 (TED), and when 'false' indicates no validation against
 the TED is required.";
}
leaf lockdown {
 type empty;
 description
 "Indicates no reoptimization to be attempted for this path.";
}
leaf path-scope {
 type identityref {
 base te-types:path-scope-type;
 }
 default "te-types:path-scope-end-to-end";
 config false;
 description
 "Path scope if segment or an end-to-end path.";
}
}

/* This grouping will be re-used in path-computation rpc */

grouping path-compute-info {
 description
 "Attributes used for path computation request.";
 uses tunnel-associations-properties;
 uses te-types:generic-path-optimization;
 leaf named-path-constraint {
 if-feature "te-types:named-path-constraints";
 type leafref {
 path "/te:te/te:globals/te:named-path-constraints/"
 + "te:named-path-constraint/te:name";
 }
 description
 "Reference to a globally defined named path constraint set.";
 }
 uses path-constraints-common;
}

/* This grouping will be re-used in path-computation rpc */

grouping path-preference {
 description
 "The path preference.";
 leaf preference {
```

```
 type uint8 {
 range "1..255";
 }
 default "1";
 description
 "Specifies a preference for this path. The lower the number
 higher the preference.";
 }
}

/* This grouping will be re-used in path-computation rpc */

grouping k-requested-paths {
 description
 "The k-shortest paths requests.";
 leaf k-requested-paths {
 type uint8;
 default "1";
 description
 "The number of k-shortest-paths requested from the path
 computation server and returned sorted by its optimization
 objective. The value 0 all possible paths.";
 }
}

grouping path-properties {
 description
 "TE computed path properties grouping.";
 uses te-types:generic-path-properties {
 augment "path-properties" {
 description
 "additional path properties returned by path computation.";
 uses te-types:te-bandwidth;
 leaf disjointness-type {
 type te-types:te-path-disjointness;
 config false;
 description
 "The type of resource disjointness.
 When reported for a primary path, it represents the
 minimum level of disjointness of all the secondary
 paths.
 When reported for a secondary path, it represents the
 disjointness of the secondary path.";
 }
 }
 }
}
```

```
grouping path-state {
 description
 "TE per path state parameters.";
 uses path-computation-response;
 uses lsp-provisioning-error-info {
 augment "lsp-provisioning-error-infos/"
 + "lsp-provisioning-error-info" {
 description
 "Augmentation of LSP provisioning information under a
 specific path.";
 leaf lsp-id {
 type uint16;
 description
 "The LSP-ID for which path computation was performed.";
 }
 }
 }
}
container lsps {
 config false;
 description
 "The TE LSPs container.";
 list lsp {
 key "node lsp-id";
 description
 "List of LSPs associated with the tunnel.";
 leaf tunnel-name {
 type leafref {
 path "/te:te/te:lsps/te:lsp/te:tunnel-name";
 }
 description "TE tunnel name.";
 }
 leaf node {
 type leafref {
 path "/te:te/te:lsps/te:lsp/te:node";
 }
 description "The node where the LSP state resides on.";
 }
 leaf lsp-id {
 type leafref {
 path "/te:te/te:lsps/te:lsp/te:lsp-id";
 }
 description "The TE LSP identifier.";
 }
 }
}

/* This grouping will be re-used in path-computation rpc */
```

```
grouping path-computation-response {
 description
 "Attributes reported by path computation response.";
 container computed-paths-properties {
 config false;
 description
 "Computed path properties container.";
 list computed-path-properties {
 key "k-index";
 description
 "List of computed paths.";
 leaf k-index {
 type uint8;
 description
 "The k-th path returned from the computation server.
 A lower k value path is more optimal than higher k
 value path(s)";
 }
 uses path-properties {
 description
 "The TE path computed properties.";
 }
 }
 }
}
container computed-path-error-infos {
 config false;
 description
 "Path computation information container.";
 list computed-path-error-info {
 description
 "List of path computation info entries.";
 leaf error-description {
 type string;
 description
 "Textual representation of the error occurred during
 path computation.";
 }
 leaf error-timestamp {
 type yang:date-and-time;
 description
 "Timestamp of last path computation attempt.";
 }
 leaf error-reason {
 type identityref {
 base path-computation-error-reason;
 }
 description
 "Reason for the path computation error.";
 }
 }
}
```

```
 }
 }
}

grouping lsp-provisioning-error-info {
 description
 "Grouping for LSP provisioning error information.";
 container lsp-provisioning-error-infos {
 config false;
 description
 "LSP provisioning error information.";
 list lsp-provisioning-error-info {
 description
 "List of LSP provisioning error info entries.";
 leaf error-description {
 type string;
 description
 "Textual representation of the error occurred during
 path computation.";
 }
 leaf error-timestamp {
 type yang:date-and-time;
 description
 "Timestamp of when the reported error occurred.";
 }
 leaf error-node-id {
 type te-types:te-node-id;
 default "0.0.0.0";
 description
 "Node identifier of node where error occurred.";
 }
 leaf error-link-id {
 type te-types:te-tp-id;
 default "0";
 description
 "Link ID where the error occurred.";
 }
 }
 }
}

grouping protection-restoration-properties-state {
 description
 "Protection parameters grouping.";
 leaf lockout-of-normal {
 type boolean;
 default "false";
 }
}
```

```
description
 "When set to 'True', it represents a lockout of normal
 traffic external command. When set to 'False', it
 represents a clear lockout of normal traffic external
 command. The lockout of normal traffic command applies
 to this Tunnel.";
reference
 "RFC4427";
}
leaf freeze {
 type boolean;
 default "false";
 description
 "When set to 'True', it represents a freeze external command.
 When set to 'False', it represents a clear freeze external
 command. The freeze command applies to all the Tunnels which
 are sharing the protection resources with this Tunnel.";
 reference
 "RFC4427";
}
leaf lsp-protection-role {
 type enumeration {
 enum working {
 description
 "A working LSP must be a primary LSP whilst a protecting
 LSP can be either a primary or a secondary LSP. Also,
 known as protected LSPs when working LSPs are associated
 with protecting LSPs.";
 }
 enum protecting {
 description
 "A secondary LSP is an LSP that has been provisioned
 in the control plane only; e.g. resource allocation
 has not been committed at the data plane.";
 }
 }
 default "working";
 description
 "LSP role type.";
 reference
 "RFC4872, section 4.2.1";
}
leaf lsp-protection-state {
 type identityref {
 base te-types:lsp-protection-state;
 }
 default "te-types:normal";
 description
```



```
 "The state of the APS state machine controlling which
 tunnels is using the resources of the protecting LSP.";
 }
 leaf protection-group-ingress-node-id {
 type te-types:te-node-id;
 default "0.0.0.0";
 description
 "Indicates the te-node-id of the protection group
 ingress node when the APS state represents an external
 command (LoP, SF, MS) applied to it or a WTR timer
 running on it. If the external command is not applied to
 the ingress node or the WTR timer is not running on it,
 this attribute is not specified. A value 0.0.0.0 is used
 when the te-node-id of the protection group ingress node is
 unknown (e.g., because the ingress node is outside the scope
 of control of the server)";
 }
 leaf protection-group-egress-node-id {
 type te-types:te-node-id;
 default "0.0.0.0";
 description
 "Indicates the te-node-id of the protection group egress node
 when the APS state represents an external command (LoP, SF,
 MS) applied to it or a WTR timer running on it. If the
 external command is not applied to the ingress node or
 the WTR timer is not running on it, this attribute is not
 specified. A value 0.0.0.0 is used when the te-node-id of
 the protection group ingress node is unknown (e.g., because
 the ingress node is outside the scope of control of the
 server)";
 }
}

grouping protection-restoration-properties {
 description
 "Protection and restoration parameters.";
 container protection {
 description
 "Protection parameters.";
 leaf enable {
 type boolean;
 default "false";
 description
 "A flag to specify if LSP protection is enabled.";
 reference
 "RFC4427";
 }
 leaf protection-type {
```

```
 type identityref {
 base te-types:lsp-protection-type;
 }
 default "te-types:lsp-protection-unprotected";
 description
 "LSP protection type.";
 }
 leaf protection-reversion-disable {
 type boolean;
 default "false";
 description
 "Disable protection reversion to working path.";
 }
 leaf hold-off-time {
 type uint32;
 units "milli-seconds";
 default "0";
 description
 "The time between the declaration of an SF or SD condition
 and the initialization of the protection switching
 algorithm.";
 reference
 "RFC4427";
 }
 leaf wait-to-revert {
 type uint16;
 units "seconds";
 description
 "Time to wait before attempting LSP reversion.";
 reference
 "RFC4427";
 }
 leaf aps-signal-id {
 type uint8 {
 range "1..255";
 }
 default "1";
 description
 "The APS signal number used to reference the traffic of
 this tunnel. The default value for normal traffic is 1.
 The default value for extra-traffic is 255. If not
 specified, non-default values can be assigned by the
 server, if and only if, the server controls both
 endpoints.";
 reference
 "RFC4427";
 }
}
```

```
container restoration {
 description
 "Restoration parameters.";
 leaf enable {
 type boolean;
 default "false";
 description
 "A flag to specify if LSP restoration is enabled.";
 reference
 "RFC4427";
 }
 leaf restoration-type {
 type identityref {
 base te-types:lsp-restoration-type;
 }
 default "te-types:lsp-restoration-restore-any";
 description
 "LSP restoration type.";
 }
 leaf restoration-scheme {
 type identityref {
 base te-types:restoration-scheme-type;
 }
 default "te-types:restoration-scheme-preconfigured";
 description
 "LSP restoration scheme.";
 }
 leaf restoration-reversion-disable {
 type boolean;
 default "false";
 description
 "Disable restoration reversion to working path.";
 }
 leaf hold-off-time {
 type uint32;
 units "milli-seconds";
 description
 "The time between the declaration of an SF or SD condition
 and the initialization of the protection switching
 algorithm.";
 reference
 "RFC4427";
 }
 leaf wait-to-restore {
 type uint16;
 units "seconds";
 description
 "Time to wait before attempting LSP restoration.";
```

```
 reference
 "RFC4427";
 }
 leaf wait-to-revert {
 type uint16;
 units "seconds";
 description
 "Time to wait before attempting LSP reversion.";
 reference
 "RFC4427";
 }
 }
 }
}

grouping tunnel-associations-properties {
 description
 "TE tunnel association grouping.";
 container association-objects {
 description
 "TE tunnel associations.";
 list association-object {
 key "association-key";
 unique "type id source/id source/type";
 description
 "List of association base objects.";
 reference
 "RFC4872";
 leaf association-key {
 type string;
 description
 "Association key used to identify a specific
 association in the list";
 }
 leaf type {
 type identityref {
 base te-types:association-type;
 }
 description
 "Association type.";
 reference
 "RFC4872";
 }
 leaf id {
 type uint16;
 description
 "Association identifier.";
 reference
 "RFC4872";
 }
 }
 }
}
```

```
 }
 container source {
 uses te-generic-node-id;
 description
 "Association source.";
 reference
 "RFC4872";
 }
 }
 list association-object-extended {
 key "association-key";
 unique
 "type id source/id source/type global-source extended-id";
 description
 "List of extended association objects.";
 reference
 "RFC6780";
 leaf association-key {
 type string;
 description
 "Association key used to identify a specific
 association in the list";
 }
 leaf type {
 type identityref {
 base te-types:association-type;
 }
 description
 "Association type.";
 reference
 "RFC4872, RFC6780";
 }
 leaf id {
 type uint16;
 description
 "Association identifier.";
 reference
 "RFC4872, RFC6780";
 }
 }
 container source {
 uses te-generic-node-id;
 description
 "Association source.";
 reference
 "RFC4872, RFC6780";
 }
 leaf global-source {
 type uint32;
```

```
 description
 "Association global source.";
 reference
 "RFC6780";
 }
 leaf extended-id {
 type yang:hex-string;
 description
 "Association extended identifier.";
 reference
 "RFC6780";
 }
}
}

/* TE tunnel configuration/state grouping */
/* These grouping will be re-used in path-computation rpc */

grouping encoding-and-switching-type {
 description
 "Common grouping to define the LSP encoding and
 switching types";
 leaf encoding {
 type identityref {
 base te-types:lsp-encoding-types;
 }
 description
 "LSP encoding type.";
 reference
 "RFC3945";
 }
 leaf switching-type {
 type identityref {
 base te-types:switching-capabilities;
 }
 description
 "LSP switching type.";
 reference
 "RFC3945";
 }
}

grouping tunnel-common-attributes {
 description
 "Common grouping to define the TE tunnel parameters";
 leaf source {
 type te-types:te-node-id;
```

```
 description
 "TE tunnel source node ID.";
 }
 leaf destination {
 type te-types:te-node-id;
 description
 "TE tunnel destination node identifier.";
 }
 leaf src-tunnel-tp-id {
 type binary;
 description
 "TE tunnel source termination point identifier.";
 }
 leaf dst-tunnel-tp-id {
 type binary;
 description
 "TE tunnel destination termination point identifier.";
 }
 leaf bidirectional {
 type boolean;
 default "false";
 description
 "Indicates a bidirectional co-routed LSP.";
 }
 }
 }

 grouping tunnel-hierarchy-properties {
 description
 "A grouping for TE tunnel hierarchy information.";
 container hierarchy {
 description
 "Container for TE hierarchy related information.";
 container dependency-tunnels {
 description
 "List of tunnels that this tunnel can be potentially
 dependent on.";
 list dependency-tunnel {
 key "name";
 description
 "A tunnel entry that this tunnel can potentially depend
 on.";
 leaf name {
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/te:name";
 require-instance false;
 }
 }
 description
 "Dependency tunnel name. The tunnel may not have been
```

```
 instantiated yet.";
 }
 uses encoding-and-switching-type;
}
}
container hierarchical-link {
 description
 "Identifies a hierarchical link (in client layer)
 that this tunnel is associated with.";
 reference
 "RFC4206";
 leaf local-te-node-id {
 type te-types:te-node-id;
 default "0.0.0.0";
 description
 "The local TE node identifier.";
 }
 leaf local-te-link-tp-id {
 type te-types:te-tp-id;
 default "0";
 description
 "The local TE link termination point identifier.";
 }
 leaf remote-te-node-id {
 type te-types:te-node-id;
 default "0.0.0.0";
 description
 "Remote TE node identifier.";
 }
 uses te-types:te-topology-identifier {
 description
 "The topology identifier where the hierarchical link
 supported by this TE tunnel is instantiated.";
 }
}
}
}

grouping tunnel-properties {
 description
 "Top level grouping for tunnel properties.";
 leaf name {
 type string;
 description
 "TE tunnel name.";
 }
 leaf alias {
 type string;
 }
}
```



```
 description
 "An alternate name of the TE tunnel that can be modified
 anytime during its lifetime.";
 }
 leaf identifier {
 type uint32;
 description
 "TE tunnel Identifier.";
 reference
 "RFC3209";
 }
 leaf color {
 type uint32;
 description "The color associated with the TE tunnel.";
 reference "RFC9012";
 }
 leaf description {
 type string;
 default "None";
 description
 "Textual description for this TE tunnel.";
 }
 leaf admin-state {
 type identityref {
 base te-types:tunnel-admin-state-type;
 }
 default "te-types:tunnel-admin-state-up";
 description
 "TE tunnel administrative state.";
 }
 leaf operational-state {
 type identityref {
 base te-types:tunnel-state-type;
 }
 config false;
 description
 "TE tunnel operational state.";
 }
 uses encoding-and-switching-type;
 uses tunnel-common-attributes;
 container controller {
 description
 "Contains tunnel data relevant to external controller(s).
 This target node may be augmented by external module(s),
 for example, to add data for PCEP initiated and/or
 delegated tunnels.";
 leaf protocol-origin {
 type identityref {
```

```
 base protocol-origin-type;
 }
 description
 "The protocol origin for instantiating the tunnel.";
 }
 leaf controller-entity-id {
 type string;
 description
 "An identifier unique within the scope of visibility that
 associated with the entity that controls the tunnel";
 reference "RFC8232";
 }
}
leaf reoptimize-timer {
 type uint16;
 units "seconds";
 description
 "Frequency of reoptimization of a traffic engineered LSP.";
}
uses tunnel-associations-properties;
uses protection-restoration-properties;
uses te-types:tunnel-constraints;
uses tunnel-hierarchy-properties;
container primary-paths {
 description
 "The set of primary paths.";
 list primary-path {
 key "name";
 description
 "List of primary paths for this tunnel.";
 uses primary-path;
 container primary-reverse-path {
 description
 "The reverse primary path properties.";
 uses primary-reverse-path;
 container candidate-secondary-reverse-paths {
 description
 "The set of referenced candidate reverse secondary
 paths from the full set of secondary reverse paths
 which may be used for this primary path.";
 list candidate-secondary-reverse-path {
 key "secondary-path";
 ordered-by user;
 description
 "List of candidate secondary reverse path(s)";
 leaf secondary-path {
 type leafref {
 path "../.../.../.../.../..."
 }
 }
 }
 }
 }
 }
}
```

```

 + "te:secondary-reverse-paths/"
 + "te:secondary-reverse-path/te:name";
 }
 description
 "A reference to the secondary reverse path that
 should be utilised when the containing primary
 reverse path option is in use.";
 }
}
}
}
container candidate-secondary-paths {
 description
 "The set of candidate secondary paths which may be used
 for this primary path. When secondary paths are
 specified in the list the path of the secondary LSP in
 use must be restricted to those path options referenced.
 The priority of the secondary paths is specified within
 the list. Higher priority values are less preferred -
 that is to say that a path with priority 0 is the most
 preferred path. In the case that the list is empty, any
 secondary path option may be utilised when the current
 primary path is in use.";
 list candidate-secondary-path {
 key "secondary-path";
 ordered-by user;
 description
 "List of candidate secondary paths for this tunnel.";
 leaf secondary-path {
 type leafref {
 path "../../../../../te:secondary-paths/"
 + "te:secondary-path/te:name";
 }
 description
 "A reference to the secondary path that should be
 utilised when the containing primary path option is
 in use.";
 }
 leaf active {
 type boolean;
 config false;
 description
 "Indicates the current active path option that has
 been selected of the candidate secondary paths.";
 }
 }
}
}
}

```

```
 }
 container secondary-paths {
 description
 "The set of secondary paths.";
 list secondary-path {
 key "name";
 description
 "List of secondary paths for this tunnel.";
 uses secondary-path;
 }
 }
 container secondary-reverse-paths {
 description
 "The set of secondary reverse paths.";
 list secondary-reverse-path {
 key "name";
 description
 "List of secondary paths for this tunnel.";
 uses secondary-reverse-path;
 }
 }
 }
}

grouping tunnel-actions {
 description
 "Tunnel actions.";
 action tunnel-action {
 description
 "Tunnel action.";
 input {
 leaf action-type {
 type identityref {
 base tunnel-actions-type;
 }
 description
 "Tunnel action type.";
 }
 }
 output {
 leaf action-result {
 type identityref {
 base te-types:te-action-result;
 }
 description
 "The result of the tunnel action operation.";
 }
 }
 }
}
```

```
}

grouping tunnel-protection-actions {
 description
 "Protection external command actions.";
 action protection-external-commands {
 input {
 leaf protection-external-command {
 type identityref {
 base te-types:protection-external-commands;
 }
 description
 "Protection external command.";
 }
 leaf protection-group-ingress-node-id {
 type te-types:te-node-id;
 description
 "When specified, indicates whether the action is
 applied on ingress node.
 By default, if neither ingress nor egress node-id
 is set, the action applies to ingress node only.";
 }
 leaf protection-group-egress-node-id {
 type te-types:te-node-id;
 description
 "When specified, indicates whether the action is
 applied on egress node.
 By default, if neither ingress nor egress node-id
 is set, the action applies to ingress node only.";
 }
 leaf path-ref {
 type path-ref;
 description
 "Indicates to which path the external command applies
 to.";
 }
 leaf traffic-type {
 type enumeration {
 enum normal-traffic {
 description
 "The manual-switch or forced-switch command applies
 to the normal traffic (this Tunnel).";
 }
 enum null-traffic {
 description
 "The manual-switch or forced-switch command applies
 to the null traffic.";
 }
 }
 }
 }
 }
}
```

```

 enum extra-traffic {
 description
 "The manual-switch or forced-switch command applies
 to the extra traffic (the extra-traffic Tunnel
 sharing protection bandwidth with this Tunnel).";
 }
 }
 description
 "Indicates whether the manual-switch or forced-switch
 commands applies to the normal traffic, the null traffic
 or the extra-traffic.";
 reference
 "RFC4427";
}
leaf extra-traffic-tunnel-ref {
 type tunnel-ref;
 description
 "In case there are multiple extra-traffic tunnels sharing
 protection bandwidth with this Tunnel (m:n protection),
 represents which extra-traffic Tunnel the manual-switch
 or forced-switch to extra-traffic command applies to.";
}
}
}

/** End of TE tunnel groupings */
/**
 * LSP related generic groupings
 */

grouping lsp-record-route-information-state {
 description
 "LSP Recorded route information grouping.";
 container lsp-record-route-information {
 description
 "RSVP recorded route object information.";
 list lsp-record-route-information {
 when "../origin-type = 'ingress'" {
 description
 "Applicable on ingress LSPs only.";
 }
 }
 key "index";
 description
 "Record route list entry.";
 uses te-types:record-route-state;
 }
}

```

```
 }

 grouping lsp-grouping {
 description
 "LSPs state operational data grouping.";
 container lsp {
 config false;
 description
 "TE LSPs state container.";
 list lsp {
 key "tunnel-name lsp-id node";
 unique "source destination tunnel-id lsp-id "
 + "extended-tunnel-id";
 description
 "List of LSPs associated with the tunnel.";
 leaf tunnel-name {
 type string;
 description "The TE tunnel name.";
 }
 leaf lsp-id {
 type uint16;
 description
 "Identifier used in the SENDER_TEMPLATE and the
 FILTER_SPEC that can be changed to allow a sender to
 share resources with itself.";
 reference
 "RFC3209";
 }
 leaf node {
 type te-types:te-node-id;
 description
 "The node where the TE LSP state resides on.";
 }
 uses lsp-properties-state;
 uses lsp-record-route-information-state;
 }
 }
 }

 /*** End of TE LSP groupings ***/
 /**
 * TE global generic groupings
 */
 /* Global named admin-groups configuration data */

 grouping named-admin-groups-properties {
 description
 "Global named administrative groups configuration
```

```
 grouping.";
 leaf name {
 type string;
 description
 "A string name that uniquely identifies a TE
 interface named admin-group.";
 }
 leaf bit-position {
 type uint32;
 description
 "Bit position representing the administrative group.";
 reference
 "RFC3209 and RFC7308";
 }
}

grouping named-admin-groups {
 description
 "Global named administrative groups configuration
 grouping.";
 container named-admin-groups {
 description
 "TE named admin groups container.";
 list named-admin-group {
 if-feature "te-types:extended-admin-groups";
 if-feature "te-types:named-extended-admin-groups";
 key "name";
 description
 "List of named TE admin-groups.";
 uses named-admin-groups-properties;
 }
 }
}

/* Global named admin-srlgs configuration data */

grouping named-srlgs {
 description
 "Global named SRLGs configuration grouping.";
 container named-srlgs {
 description
 "TE named SRLGs container.";
 list named-srlg {
 if-feature "te-types:named-srlg-groups";
 key "name";
 description
 "A list of named SRLG groups.";
 leaf name {
```



```
 type string;
 description
 "A string name that uniquely identifies a TE
 interface named SRLG.";
 }
 leaf value {
 type te-types:srlg;
 description
 "An SRLG value.";
 }
 leaf cost {
 type uint32;
 description
 "SRLG associated cost. Used during path to append
 the path cost when traversing a link with this SRLG.";
 }
}
}
}

/* Global named paths constraints configuration data */

grouping path-constraints-common {
 description
 "Global named path constraints configuration
 grouping.";
 uses te-types:common-path-constraints-attributes {
 description
 "The constraints applicable to the path. This includes:
 - The path bandwidth constraint
 - The path link protection type constraint
 - The path setup/hold priority constraint
 - path signaling type constraint
 - path metric bounds constraint. The unit of path metric
 bound is interpreted in the context of the metric-type.
 For example for metric-type 'path-metric-loss', the bound
 is multiples of the basic unit 0.000003% as described
 in RFC7471 for OSPF, and RFC8570 for ISIS.
 - path affinity constraints
 - path SRLG constraints";
 }
 uses te-types:generic-path-disjointness;
 uses te-types:path-constraints-route-objects;
 container path-in-segment {
 presence "The end-to-end tunnel starts in a previous domain;
 this tunnel is a segment in the current domain.";
 description
 }
}
```

```
 "If an end-to-end tunnel crosses multiple domains using
 the same technology, some additional constraints have to be
 taken in consideration in each domain.
 This TE tunnel segment is stitched to the upstream TE tunnel
 segment.";
 uses te-types:label-set-info;
}
container path-out-segment {
 presence
 "The end-to-end tunnel is not terminated in this domain;
 this tunnel is a segment in the current domain.";
 description
 "If an end-to-end tunnel crosses multiple domains using
 the same technology, some additional constraints have to be
 taken in consideration in each domain.
 This TE tunnel segment is stitched to the downstream TE
 tunnel segment.";
 uses te-types:label-set-info;
}
}

grouping named-path-constraints {
 description
 "Global named path constraints configuration
 grouping.";
 container named-path-constraints {
 description
 "TE named path constraints container.";
 list named-path-constraint {
 if-feature "te-types:named-path-constraints";
 key "name";
 leaf name {
 type string;
 description
 "A string name that uniquely identifies a
 path constraint set.";
 }
 uses path-constraints-common;
 description
 "A list of named path constraints.";
 }
 }
}

/* TE globals container data */

grouping globals-grouping {
 description
```

```
 "Globals TE system-wide configuration data grouping.";
 container globals {
 description
 "Globals TE system-wide configuration data container.";
 uses named-admin-groups;
 uses named-srlgs;
 uses named-path-constraints;
 }
}

/* TE tunnels container data */

grouping tunnels-grouping {
 description
 "Tunnels TE configuration data grouping.";
 container tunnels {
 description
 "Tunnels TE configuration data container.";
 list tunnel {
 key "name";
 description
 "The list of TE tunnels.";
 uses tunnel-properties;
 uses tunnel-actions;
 uses tunnel-protection-actions;
 }
 }
}

/* TE LSPs ephemeral state container data */

grouping lsp-properties-state {
 description
 "LSPs state operational data grouping.";
 leaf source {
 type te-types:te-node-id;
 description
 "Tunnel sender address extracted from
 SENDER_TEMPLATE object.";
 reference
 "RFC3209";
 }
 leaf destination {
 type te-types:te-node-id;
 description
 "The tunnel endpoint address extracted from SESSION object.";
 reference
 "RFC3209";
 }
}
```

```
 }
 leaf tunnel-id {
 type uint16;
 description
 "The tunnel identifier used in the SESSION that remains
 constant over the life of the tunnel.";
 reference
 "RFC3209";
 }
 leaf extended-tunnel-id {
 type yang:dotted-quad;
 description
 "The LSP Extended Tunnel ID.";
 reference
 "RFC3209";
 }
 leaf operational-state {
 type identityref {
 base te-types:lsp-state-type;
 }
 description
 "The LSP operational state.";
 }
 leaf signaling-type {
 type identityref {
 base te-types:path-signaling-type;
 }
 description
 "The signaling protocol used to set up this LSP.";
 }
 leaf origin-type {
 type enumeration {
 enum ingress {
 description
 "Origin ingress.";
 }
 enum egress {
 description
 "Origin egress.";
 }
 enum transit {
 description
 "Origin transit.";
 }
 }
 default "ingress";
 description
 "The origin of the LSP relative to the location of the local
```

```
 switch in the path.";
 }
 leaf lsp-resource-status {
 type enumeration {
 enum primary {
 description
 "A primary LSP is a fully established LSP for which the
 resource allocation has been committed at the data
 plane.";
 }
 enum secondary {
 description
 "A secondary LSP is an LSP that has been provisioned
 in the control plane only; e.g. resource allocation
 has not been committed at the data plane.";
 }
 }
 default "primary";
 description
 "LSP resource allocation state.";
 reference
 "RFC4872, section 4.2.1";
 }
 uses protection-restoration-properties-state;
}

/** End of TE global groupings */
/**
 * TE container
 */

container te {
 presence "Enable TE feature.";
 description
 "TE global container.";
 /* TE Global Data */
 uses globals-grouping;

 /* TE Tunnel Data */
 uses tunnels-grouping;

 /* TE LSPs Data */
 uses lsps-grouping;
}

/* TE Tunnel RPCs/execution Data */

rpc tunnels-path-compute {
```

```
description
 "TE tunnels RPC nodes.";
input {
 container path-compute-info {
 /*
 * An external path compute module may augment this
 * target.
 */
 description
 "RPC input information.";
 }
}
output {
 container path-compute-result {
 /*
 * An external path compute module may augment this
 * target.
 */
 description
 "RPC output information.";
 }
}

rpc tunnels-actions {
 description
 "TE tunnels actions RPC";
 input {
 container tunnel-info {
 description
 "TE tunnel information.";
 choice filter-type {
 mandatory true;
 description
 "Filter choice.";
 case all-tunnels {
 leaf all {
 type empty;
 mandatory true;
 description
 "Apply action on all TE tunnels.";
 }
 }
 case one-tunnel {
 leaf tunnel {
 type tunnel-ref;
 description
 "Apply action on the specific TE tunnel.";
 }
 }
 }
 }
 }
}
```

```

 }
 }
}
container action-info {
 description
 "TE tunnel action information.";
 leaf action {
 type identityref {
 base tunnel-actions-type;
 }
 description
 "The action type.";
 }
 leaf disruptive {
 when "derived-from-or-self(..../action, "
 + "'te:tunnel-action-reoptimize')";
 type empty;
 description
 "Specifies whether or not the reoptimization action
 is allowed to be disruptive.";
 }
}
}
output {
 leaf action-result {
 type identityref {
 base te-types:te-action-result;
 }
 description
 "The result of the tunnel action operation.";
 }
}
}
}
<CODE ENDS>

```

Figure 9: TE Tunnel data model YANG module

## 6. TE Device YANG Model

The device TE YANG module ('ietf-te-device') models data that is specific to managing a TE device. This module augments the generic TE YANG module.

## 6.1. Module Structure

### 6.1.1. TE Interfaces

This branch of the model manages TE interfaces that are present on a device. Examples of TE interface properties are:

- \* Maximum reservable bandwidth, bandwidth constraints (BC)
- \* Flooding parameters
  - Flooding intervals and threshold values
- \* interface attributes
  - (Extended) administrative groups
  - SRLG values
  - TE metric value
- \* Fast reroute backup tunnel properties (such as static, auto-tunnel)

The derived state associated with interfaces is grouped under the interface "state" sub-container as shown in Figure 10. This covers state data such as:

- \* Bandwidth information: maximum bandwidth, available bandwidth at different priorities and for each class-type (CT)
- \* List of admitted LSPs
  - Name, bandwidth value and pool, time, priority
- \* Statistics: state counters, flooding counters, admission counters (accepted/rejected), preemption counters
- \* Adjacency information
  - Neighbor address
  - Metric value



```

module: ietf-te-device
 augment /te:te:
 +--rw interfaces
 .
 +-- rw te-dev:te-attributes
 <<intended configuration>>
 .
 +-- ro state
 <<derived state associated with the TE interface>>

```

Figure 10: TE interface state YANG subtree

## 6.2. Tree Diagram

Figure 11 shows the tree diagram of the device TE YANG model defined in modules 'ietf-te.yang'.

```

module: ietf-te-device
 augment /te:te:
 +--rw interfaces
 |
 | +--rw threshold-type? enumeration
 | +--rw delta-percentage? rt-types:percentage
 | +--rw threshold-specification? enumeration
 | +--rw up-thresholds* rt-types:percentage
 | +--rw down-thresholds* rt-types:percentage
 | +--rw up-down-thresholds* rt-types:percentage
 | +--rw interface* [interface]
 | +--rw interface if:interface-ref
 | +--rw te-metric?
 | |
 | | te-types:te-metric
 | +--rw (admin-group-type)?
 | |
 | | +--:(value-admin-groups)
 | | |
 | | | +--rw (value-admin-group-type)?
 | | | |
 | | | | +--:(admin-groups)
 | | | | |
 | | | | | +--rw admin-group?
 | | | | | |
 | | | | | | te-types:admin-group
 | | | | | +--:(extended-admin-groups)
 | | | | | | {te-types:extended-admin-groups}?
 | | | | | | +--rw extended-admin-group?
 | | | | | | |
 | | | | | | | te-types:extended-admin-group
 | | | | | +--:(named-admin-groups)
 | | | | | | +--rw named-admin-groups* [named-admin-group]
 | | | | | | |
 | | | | | | | {te-types:extended-admin-groups, te-types:named-
 | | | | | | | extended-admin-groups}?
 | | | | | | | +--rw named-admin-group leafref
 | | | | | +--rw (srlg-type)?
 | | | | | | +--:(value-srlgs)
 | | | | | | |
 | | | | | | | +--rw values* [value]

```

```

 | +---rw value uint32
 +---:(named-srlgs)
 | +---rw named-srlgs* [named-srlg]
 | | {te-types:named-srlg-groups}?
 | +---rw named-srlg leafref
+---rw threshold-type? enumeration
+---rw delta-percentage?
| rt-types:percentage
+---rw threshold-specification? enumeration
+---rw up-thresholds*
| rt-types:percentage
+---rw down-thresholds*
| rt-types:percentage
+---rw up-down-thresholds*
| rt-types:percentage
+---rw switching-capabilities* [switching-capability]
| +---rw switching-capability identityref
| +---rw encoding? identityref
+---ro state
 +---ro te-advertisements-state
 | +---ro flood-interval? uint32
 | +---ro last-flooded-time? uint32
 | +---ro next-flooded-time? uint32
 | +---ro last-flooded-trigger? enumeration
 | +---ro advertised-level-areas* [level-area]
 | +---ro level-area uint32
+---rw performance-thresholds
augment /te:te/te:globals:
+---rw lsp-install-interval? uint32
+---rw lsp-cleanup-interval? uint32
+---rw lsp-invalidation-interval? uint32
augment /te:te/te:tunnels/te:tunnel:
+---rw path-invalidation-action? identityref
+---rw lsp-install-interval? uint32
+---rw lsp-cleanup-interval? uint32
+---rw lsp-invalidation-interval? uint32
augment /te:te/te:lsps/te:lsp:
+---ro lsp-timers
| +---ro life-time? uint32
| +---ro time-to-install? uint32
| +---ro time-to-destroy? uint32
+---ro downstream-info
| +---ro nhop? te-types:te-tp-id
| +---ro outgoing-interface? if:interface-ref
| +---ro neighbor
| | +---ro id? te-gen-node-id
| | +---ro type? enumeration
+---ro label? rt-types:generalized-label

```

```

+--ro upstream-info
 +--ro phop? te-types:te-tp-id
 +--ro neighbor
 | +--ro id? te-gen-node-id
 | +--ro type? enumeration
 +--ro label? rt-types:generalized-label

rpcs:
 +---x link-state-update
 +---w input
 +---w (filter-type)
 +---:(match-all)
 | +---w all empty
 +---:(match-one-interface)
 +---w interface? if:interface-ref

```

Figure 11: TE Tunnel device model YANG tree diagram

### 6.3. YANG Module

The device TE YANG module 'ietf-te-device' imports the following module(s):

- \* ietf-yang-types and ietf-inet-types defined in [RFC6991]
- \* ietf-interfaces defined in [RFC8343]
- \* ietf-routing-types defined in [RFC8294]
- \* ietf-te-types defined in [RFC8776]
- \* ietf-te defined in this document

```

<CODE BEGINS> file "ietf-te-device@2021-10-22.yang"
module ietf-te-device {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te-device";

 /* Replace with IANA when assigned */

 prefix te-dev;

 /* Import TE module */

 import ietf-te {
 prefix te;
 reference
 "draft-ietf-teas-yang-te: A YANG Data Model for Traffic

```

```
 Engineering Tunnels and Interfaces";
}

/* Import TE types */

import ietf-te-types {
 prefix te-types;
 reference
 "RFC8776: Common YANG Data Types for Traffic Engineering.";
}
import ietf-interfaces {
 prefix if;
 reference
 "RFC8343: A YANG Data Model for Interface Management";
}
import ietf-routing-types {
 prefix rt-types;
 reference
 "RFC8294: Common YANG Data Types for the Routing Area";
}

organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";
contact
 "WG Web: <http://tools.ietf.org/wg/teas/>
 WG List: <mailto:teas@ietf.org>

 Editor: Tarek Saad
 <mailto:tsaad@juniper.net>

 Editor: Rakesh Gandhi
 <mailto:rgandhi@cisco.com>

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 <mailto:vbeeram@juniper.net>

 Editor: Himanshu Shah
 <mailto:hshah@ciena.com>

 Editor: Xufeng Liu
 <mailto:xufeng.liu.ietf@gmail.com>

 Editor: Igor Bryskin
 <mailto:i_bryskin@yahoo.com>";
description
 "YANG data module for TE device configurations,
 state, and RPCs. The model fully conforms to the
```

Network Management Datastore Architecture (NMDA).

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identified as authors of the code. All rights reserved.

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set forth in Section 4.c of the IETF Trust's Legal Provisions  
Relating to IETF Documents  
(<https://trustee.ietf.org/license-info>).  
This version of this YANG module is part of RFC XXXX; see  
the RFC itself for full legal notices.";

```
// RFC Ed.: replace XXXX with actual RFC number and remove this
// note.
// RFC Ed.: update the date below with the date of RFC publication
// and remove this note.
```

```
revision 2021-10-22 {
 description
 "Latest update to TE device YANG module.";
 reference
 "RFCXXXX: A YANG Data Model for Traffic Engineering Tunnels
 and Interfaces";
}
```

```
/**
 * TE LSP device state grouping
 */
```

```
grouping lsps-device-info {
 description
 "TE LSP device state grouping.";
 container lsp-timers {
 when "../te:origin-type = 'ingress'" {
 description
 "Applicable to ingress LSPs only.";
 }
 description
 "Ingress LSP timers.";
 leaf life-time {
 type uint32;
 units "seconds";
 description
 "TE LSP lifetime.";
 }
 leaf time-to-install {
```

```
 type uint32;
 units "seconds";
 description
 "TE LSP installation delay time.";
 }
 leaf time-to-destroy {
 type uint32;
 units "seconds";
 description
 "TE LSP expiration delay time.";
 }
}
container downstream-info {
 when "../te:origin-type != 'egress'" {
 description
 "Downstream information of the LSP.";
 }
 description
 "downstream information.";
 leaf nhop {
 type te-types:te-tp-id;
 description
 "downstream next-hop address.";
 }
 leaf outgoing-interface {
 type if:interface-ref;
 description
 "downstream interface.";
 }
 container neighbor {
 uses te:te-generic-node-id;
 description
 "downstream neighbor address.";
 }
 leaf label {
 type rt-types:generalized-label;
 description
 "downstream label.";
 }
}
container upstream-info {
 when "../te:origin-type != 'ingress'" {
 description
 "Upstream information of the LSP.";
 }
 description
 "upstream information.";
 leaf phop {
```

```
 type te-types:te-tp-id;
 description
 "upstream next-hop or previous-hop address.";
 }
 container neighbor {
 uses te:te-generic-node-id;
 description
 "upstream neighbor address.";
 }
 leaf label {
 type rt-types:generalized-label;
 description
 "upstream label.";
 }
}

/**
 * Device general groupings.
 */

grouping lsp-device-timers {
 description
 "Device TE LSP timers configs.";
 leaf lsp-install-interval {
 type uint32;
 units "seconds";
 description
 "TE LSP installation delay time.";
 }
 leaf lsp-cleanup-interval {
 type uint32;
 units "seconds";
 description
 "TE LSP cleanup delay time.";
 }
 leaf lsp-invalidation-interval {
 type uint32;
 units "seconds";
 description
 "TE LSP path invalidation before taking action delay time.";
 }
}

/**
 * TE global device groupings
 */
/* TE interface container data */
```

```
grouping interfaces-grouping {
 description
 "TE interface configuration data grouping.";
 container interfaces {
 description
 "Configuration data model for TE interfaces.";
 uses te-all-attributes;
 list interface {
 key "interface";
 description
 "TE interfaces.";
 leaf interface {
 type if:interface-ref;
 description
 "TE interface name.";
 }
 /* TE interface parameters */
 uses te-attributes;
 }
 }
}

/**
 * TE interface device groupings
 */

grouping te-admin-groups-config {
 description
 "TE interface affinities grouping.";
 choice admin-group-type {
 description
 "TE interface administrative groups
 representation type.";
 case value-admin-groups {
 choice value-admin-group-type {
 description
 "choice of admin-groups.";
 case admin-groups {
 description
 "Administrative group/Resource
 class/Color.";
 leaf admin-group {
 type te-types:admin-group;
 description
 "TE interface administrative group.";
 }
 }
 }
 case extended-admin-groups {
```



```
 if-feature "te-types:extended-admin-groups";
 description
 "Extended administrative group/Resource
 class/Color.";
 leaf extended-admin-group {
 type te-types:extended-admin-group;
 description
 "TE interface extended administrative group.";
 }
 }
}
}
case named-admin-groups {
 list named-admin-groups {
 if-feature "te-types:extended-admin-groups";
 if-feature "te-types:named-extended-admin-groups";
 key "named-admin-group";
 description
 "A list of named admin-group entries.";
 leaf named-admin-group {
 type leafref {
 path "../..../te:globals/"
 + "te:named-admin-groups/te:named-admin-group/"
 + "te:name";
 }
 description
 "A named admin-group entry.";
 }
 }
}
}
}

/* TE interface SRLGs */

grouping te-srlgs-config {
 description
 "TE interface SRLG grouping.";
 choice srlg-type {
 description
 "Choice of SRLG configuration.";
 case value-srlgs {
 list values {
 key "value";
 description
 "List of SRLG values that
 this link is part of.";
 leaf value {
```

```
 type uint32 {
 range "0..4294967295";
 }
 description
 "Value of the SRLG";
 }
}
}
case named-srlgs {
 list named-srlgs {
 if-feature "te-types:named-srlg-groups";
 key "named-srlg";
 description
 "A list of named SRLG entries.";
 leaf named-srlg {
 type leafref {
 path "../..../te:globals/"
 + "te:named-srlgs/te:named-srlg/te:name";
 }
 description
 "A named SRLG entry.";
 }
 }
}
}
}
}

grouping te-igp-flooding-bandwidth-config {
 description
 "Configurable items for igp flooding bandwidth
 threshold configuration.";
 leaf threshold-type {
 type enumeration {
 enum delta {
 description
 "'delta' indicates that the local
 system should flood IGP updates when a
 change in reserved bandwidth >= the specified
 delta occurs on the interface.";
 }
 enum threshold-crossed {
 description
 "THRESHOLD-CROSSED indicates that
 the local system should trigger an update (and
 hence flood) the reserved bandwidth when the
 reserved bandwidth changes such that it crosses,
 or becomes equal to one of the threshold values.";
 }
 }
 }
}
```

```
}
description
 "The type of threshold that should be used to specify the
 values at which bandwidth is flooded. 'delta' indicates that
 the local system should flood IGP updates when a change in
 reserved bandwidth >= the specified delta occurs on the
 interface. Where 'threshold-crossed' is specified, the local
 system should trigger an update (and hence flood) the
 reserved bandwidth when the reserved bandwidth changes such
 that it crosses, or becomes equal to one of the threshold
 values."
}
leaf delta-percentage {
 when "../threshold-type = 'delta'" {
 description
 "The percentage delta can only be specified when the
 threshold type is specified to be a percentage delta of
 the reserved bandwidth."
 }
 type rt-types:percentage;
 description
 "The percentage of the maximum-reservable-bandwidth
 considered as the delta that results in an IGP update
 being flooded."
}
leaf threshold-specification {
 when "../threshold-type = 'threshold-crossed'" {
 description
 "The selection of whether mirrored or separate threshold
 values are to be used requires user specified thresholds
 to be set."
 }
 type enumeration {
 enum mirrored-up-down {
 description
 "mirrored-up-down indicates that a single set of
 threshold values should be used for both increasing
 and decreasing bandwidth when determining whether
 to trigger updated bandwidth values to be flooded
 in the IGP TE extensions."
 }
 enum separate-up-down {
 description
 "separate-up-down indicates that a separate
 threshold values should be used for the increasing
 and decreasing bandwidth when determining whether
 to trigger updated bandwidth values to be flooded
 in the IGP TE extensions."
 }
 }
}
```

```
 }
 }
 description
 "This value specifies whether a single set of threshold
 values should be used for both increasing and decreasing
 bandwidth when determining whether to trigger updated
 bandwidth values to be flooded in the IGP TE extensions.
 'mirrored-up-down' indicates that a single value (or set of
 values) should be used for both increasing and decreasing
 values, where 'separate-up-down' specifies that the
 increasing and decreasing values will be separately
 specified."
 }
 leaf-list up-thresholds {
 when "../threshold-type = 'threshold-crossed'"
 + "and ../threshold-specification = 'separate-up-down'" {
 description
 "A list of up-thresholds can only be specified when the
 bandwidth update is triggered based on crossing a
 threshold and separate up and down thresholds are
 required."
 }
 type rt-types:percentage;
 description
 "The thresholds (expressed as a percentage of the maximum
 reservable bandwidth) at which bandwidth updates are to be
 triggered when the bandwidth is increasing."
 }
 }
 leaf-list down-thresholds {
 when "../threshold-type = 'threshold-crossed'"
 + "and ../threshold-specification = 'separate-up-down'" {
 description
 "A list of down-thresholds can only be specified when the
 bandwidth update is triggered based on crossing a
 threshold and separate up and down thresholds are
 required."
 }
 type rt-types:percentage;
 description
 "The thresholds (expressed as a percentage of the maximum
 reservable bandwidth) at which bandwidth updates are to be
 triggered when the bandwidth is decreasing."
 }
 }
 }
 leaf-list up-down-thresholds {
 when "../threshold-type = 'threshold-crossed'"
 + "and ../threshold-specification = 'mirrored-up-down'" {
 description
 "A list of thresholds corresponding to both increasing
```

```
 and decreasing bandwidths can be specified only when an
 update is triggered based on crossing a threshold, and
 the same up and down thresholds are required.";
 }
 type rt-types:percentage;
 description
 "The thresholds (expressed as a percentage of the maximum
 reservable bandwidth of the interface) at which bandwidth
 updates are flooded - used both when the bandwidth is
 increasing and decreasing.";
}
}

/* TE interface metric */

grouping te-metric-config {
 description
 "TE interface metric grouping.";
 leaf te-metric {
 type te-types:te-metric;
 description
 "TE interface metric.";
 }
}

/* TE interface switching capabilities */

grouping te-switching-cap-config {
 description
 "TE interface switching capabilities.";
 list switching-capabilities {
 key "switching-capability";
 description
 "List of interface capabilities for this interface.";
 leaf switching-capability {
 type identityref {
 base te-types:switching-capabilities;
 }
 description
 "Switching Capability for this interface.";
 }
 leaf encoding {
 type identityref {
 base te-types:lsp-encoding-types;
 }
 description
 "Encoding supported by this interface.";
 }
 }
}
```

```
 }
 }

 grouping te-advertisements-state {
 description
 "TE interface advertisements state grouping.";
 container te-advertisements-state {
 description
 "TE interface advertisements state container.";
 leaf flood-interval {
 type uint32;
 description
 "The periodic flooding interval.";
 }
 leaf last-flooded-time {
 type uint32;
 units "seconds";
 description
 "Time elapsed since last flooding in seconds.";
 }
 leaf next-flooded-time {
 type uint32;
 units "seconds";
 description
 "Time remained for next flooding in seconds.";
 }
 leaf last-flooded-trigger {
 type enumeration {
 enum link-up {
 description
 "Link-up flooding trigger.";
 }
 enum link-down {
 description
 "Link-down flooding trigger.";
 }
 enum threshold-up {
 description
 "Bandwidth reservation up threshold.";
 }
 enum threshold-down {
 description
 "Bandwidth reservation down threshold.";
 }
 enum bandwidth-change {
 description
 "Bandwidth capacity change.";
 }
 }
 }
 }
 }
}
```

```
 enum user-initiated {
 description
 "Initiated by user.";
 }
 enum srlg-change {
 description
 "SRLG property change.";
 }
 enum periodic-timer {
 description
 "Periodic timer expired.";
 }
 }
 default "periodic-timer";
 description
 "Trigger for the last flood.";
}
list advertised-level-areas {
 key "level-area";
 description
 "List of level-areas that the TE interface is advertised
 in.";
 leaf level-area {
 type uint32;
 description
 "The IGP area or level where the TE interface link state
 is advertised in.";
 }
}
}
}

/* TE interface attributes grouping */

grouping te-attributes {
 description
 "TE attributes configuration grouping.";
 uses te-metric-config;
 uses te-admin-groups-config;
 uses te-srlgs-config;
 uses te-igp-flooding-bandwidth-config;
 uses te-switching-cap-config;
 container state {
 config false;
 description
 "State parameters for interface TE metric.";
 uses te-advertisements-state;
 }
}
```

```
}

grouping te-all-attributes {
 description
 "TE attributes configuration grouping for all
 interfaces.";
 uses te-igp-flooding-bandwidth-config;
}

/** End of TE interfaces device groupings */
/**
 * TE device augmentations
 */

augment "/te:te" {
 description
 "TE global container.";
 /* TE Interface Configuration Data */
 uses interfaces-grouping;
 container performance-thresholds {
 description
 "Performance parameters configurable thresholds.";
 }
}

/* TE globals device augmentation */

augment "/te:te/te:globals" {
 description
 "Global TE device specific configuration parameters.";
 uses lsp-device-timers;
}

/* TE tunnels device configuration augmentation */

augment "/te:te/te:tunnels/te:tunnel" {
 description
 "Tunnel device dependent augmentation.";
 leaf path-invalidation-action {
 type identityref {
 base te-types:path-invalidation-action-type;
 }
 description
 "Tunnel path invalidation action.";
 }
 uses lsp-device-timers;
}
```



```

/* TE LSPs device state augmentation */

augment "/te:te/te:lsps/te:lsp" {
 description
 "TE LSP device dependent augmentation.";
 uses lsp-device-info;
}

/* TE interfaces RPCs/execution Data */

rpc link-state-update {
 description
 "Triggers a link state update for the specific interface.";
 input {
 choice filter-type {
 mandatory true;
 description
 "Filter choice.";
 case match-all {
 leaf all {
 type empty;
 mandatory true;
 description
 "Match all TE interfaces.";
 }
 }
 case match-one-interface {
 leaf interface {
 type if:interface-ref;
 description
 "Match a specific TE interface.";
 }
 }
 }
 }
}
}

<CODE ENDS>

```

Figure 12: TE device data model YANG module

## 7. Notifications

Notifications are a key component of any topology data model.

[RFC8639] and [RFC8641] define a subscription mechanism and a push mechanism for YANG datastores. These mechanisms currently allow the user to:

- \* Subscribe to notifications on a per-client basis.
- \* Specify subtree filters or XML Path Language (XPath) filters so that only contents of interest will be sent.
- \* Specify either periodic or on-demand notifications.

## 8. TE Generic and Helper YANG Modules

## 9. IANA Considerations

This document registers the following URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registrations are requested to be made.

URI: urn:ietf:params:xml:ns:yang:ietf-te  
Registrant Contact: The IESG.  
XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-te-device  
Registrant Contact: The IESG.  
XML: N/A, the requested URI is an XML namespace.

This document registers two YANG modules in the YANG Module Names registry [RFC6020].

Name: ietf-te  
Namespace: urn:ietf:params:xml:ns:yang:ietf-te  
Prefix: te  
Reference: RFCXXXX

Name: ietf-te-device  
Namespace: urn:ietf:params:xml:ns:yang:ietf-te-device  
Prefix: te-device  
Reference: RFCXXXX

## 10. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

`"/te/globals"`: This module specifies the global TE configurations on a device. Unauthorized access to this container could cause the device to ignore packets it should receive and process.

`"/te/tunnels"`: This list specifies the configuration and state of TE Tunnels present on the device or controller. Unauthorized access to this list could cause the device to ignore packets it should receive and process. An attacker may also use state to derive information about the network topology, and subsequently orchestrate further attacks.

`"/te/interfaces"`: This list specifies the configuration and state TE interfaces on a device. Unauthorized access to this list could cause the device to ignore packets it should receive and process.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. These are the subtrees and data nodes and their sensitivity/vulnerability:

`"/te/lspss"`: this list contains information state about established LSPs in the network. An attacker can use this information to derive information about the network topology, and subsequently orchestrate further attacks.

Some of the RPC operations in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control access to these operations. These are the operations and their sensitivity/vulnerability:

`"/te/tunnels-actions"`: using this RPC, an attacker can modify existing paths that may be carrying live traffic, and hence result to interruption to services carried over the network.

`"/te/tunnels-path-compute"`: using this RPC, an attacker can retrieve secured information about the network provider which can be used to orchestrate further attacks.

The security considerations spelled out in the YANG 1.1 specification [RFC7950] apply for this document as well.

## 11. Acknowledgement

The authors would like to thank the members of the multi-vendor YANG design team who are involved in the definition of this model.

The authors would like to thank Tom Petch for reviewing and providing useful feedback about the document. The authors would also like to thank Loa Andersson, Lou Berger, Sergio Belotti, Italo Busi, Carlo Perocchio, Francesco Lazzeri, Aihua Guo, Dhruv Dhody, and Raqib Jones for providing useful feedback on this document.

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## 13. Appendix A: Data Tree Examples

This section contains examples of use of the model with RESTCONF [RFC8040] and JSON encoding.

For the example we will use a 4 node MPLS network where RSVP-TE MPLS Tunnels can be setup. The loopbacks of each router are shown. The network in Figure 13 will be used in the examples described in the following sections.

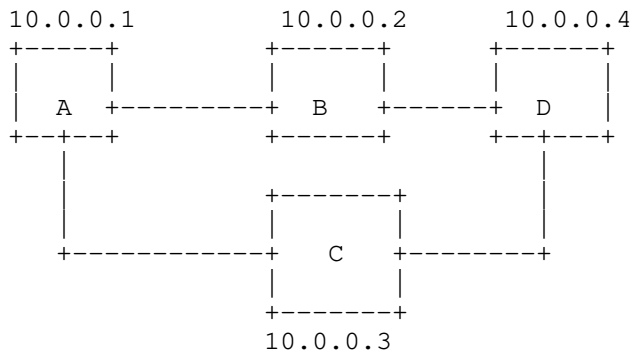


Figure 13: TE network used in data tree examples

### 13.1. Basic Tunnel Setup

This example uses the TE Tunnel YANG data model defined in this document to create an RSVP-TE signaled Tunnel of packet LSP encoding type. First, the TE Tunnel is created with no specific restrictions or constraints (e.g., protection or restoration). The TE Tunnel ingresses on router A and egresses on router D.

In this case, the TE Tunnel is created without specifying additional information about the primary paths.

```

POST /restconf/data/ietf-te:te/tunnels HTTP/1.1
Host: example.com
Accept: application/yang-data+json
Content-Type: application/yang-data+json

{
 "ietf-te:tunnel": [
 {
 "name": "Example_LSP_Tunnel_A_2",
 "encoding": "te-types:lsp-encoding-packet",
 "admin-state": "te-types:tunnel-state-up",
 "source": "10.0.0.1",
 "destination": "10.0.0.4",
 "bidirectional": "false",
 "signaling-type": "te-types:path-setup-rsvp"
 }
]
}

```

### 13.2. Global Named Path Constraints

This example uses the YANG data model to create a 'named path constraint' that can be reference by TE Tunnels. The path constraint, in this case, limits the TE Tunnel hops for the computed path.

```
POST /restconf/data/ietf-te:te/globals/named-path-constraints HTTP/1.1
```

```
Host: example.com
```

```
Accept: application/yang-data+json
```

```
Content-Type: application/yang-data+json
```

```
{
 "ietf-te:named-path-constraint": {
 "name": "max-hop-3",
 "path-metric-bounds": {
 "path-metric-bound": {
 "metric-type": "te-types:path-metric-hop",
 "upper-bound": "3"
 }
 }
 }
}
```

### 13.3. Tunnel with Global Path Constraint

In this example, the previously created 'named path constraint' is applied to the TE Tunnel created in Section 13.1.

```
POST /restconf/data/ietf-te:te/tunnels HTTP/1.1
Host: example.com
Accept: application/yang-data+json
Content-Type: application/yang-data+json

{
 "ietf-te:ietf-tunnel": [
 {
 "name": "Example_LSP_Tunnel_A_4_1",
 "encoding": "te-types:lsp-encoding-packet",
 "description": "Simple_LSP_with_named_path",
 "admin-state": "te-types:tunnel-state-up",
 "source": "10.0.0.1",
 "destination": "10.0.0.4",
 "signaling-type": "path-setup-rsvp",
 "bidirectional": "false",
 "primary-paths": [
 {
 "primary-path": {
 "name": "Simple_LSP_1",
 "use-path-computation": "true",
 "named-path-constraint": "max-hop-3"
 }
 }
]
 }
]
}
```

#### 13.4. Tunnel with Per-tunnel Path Constraint

In this example, the a per tunnel path constraint is explicitly indicated under the TE Tunnel created in Section 13.1 to constrain the computed path for the tunnel.

```
POST /restconf/data/ietf-te:te/tunnels HTTP/1.1
Host: example.com
Accept: application/yang-data+json
Content-Type: application/yang-data+json

{
 "ietf-te:tunnel": [
 {
 "name": "Example_LSP_Tunnel_A_4_2",
 "encoding": "te-types:lsp-encoding-packet",
 "admin-state": "te-types:tunnel-state-up",
 "source": "10.0.0.1",
 "destination": "10.0.0.4",
 "bidirectional": "false",
 "signaling-type": "te-types:path-setup-rsvp",
 "primary-paths": {
 "primary-path": [
 {
 "name": "path1",
 "path-metric-bounds": {
 "path-metric-bound": [
 {
 "metric-type": "te-types:path-metric-hop",
 "upper-bound": "3"
 }
]
 }
 }
]
 }
 }
]
}
```

### 13.5. Tunnel State

In this example, the 'GET' query is sent to return the state stored about the tunnel.

```
GET /restconf/data/ietf-te:te/tunnels/tunnel="Example_LSP_Tunnel_A_4_1"
/p2p-primary-paths/ HTTP/1.1
Host: example.com
Accept: application/yang-data+json
```

The request, with status code 200 would include, for example, the following json:



```
{
 "ietf-te:primary-paths": {
 "primary-path": [
 {
 "name": "path1",
 "path-computation-method": "te-types:path-locally-computed",
 "computed-paths-properties": {
 "computed-path-properties": [
 {
 "k-index": "1",
 "path-properties": {
 "path-route-objects": {
 "path-route-object": [
 {
 "index": "1",
 "numbered-node-hop": {
 "node-id": "10.0.0.2"
 }
 },
 {
 "index": "2",
 "numbered-node-hop": {
 "node-id": "10.0.0.4"
 }
 }
]
 }
 }
 }
]
 }
 }
]
 },
 "lsp": {
 "lsp": [
 {
 "tunnel-name": "Example_LSP_Tunnel_A_4_1",
 "node": "10.0.0.1 ",
 "lsp-id": "25356"
 }
]
 }
}
```

## 14. References

### 14.1. Normative References

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draft-ietf-teas-yang-te-topo-22

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## Abstract

This document defines a YANG data model for representing, retrieving and manipulating Traffic Engineering (TE) Topologies. The model serves as a base model that other technology specific TE Topology models can augment.

## Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

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## 1. Introduction

The Traffic Engineering Database (TED) is an essential component of Traffic Engineered (TE) systems that are based on MPLS-TE [RFC2702] and GMPLS [RFC3945]. The TED is a collection of all TE information about all TE nodes and TE links in the network. The TE Topology is a schematic arrangement of TE nodes and TE links present in a given TED. There could be one or more TE Topologies present in a given Traffic Engineered system. A TE Topology is the topology on which path computational algorithms are run to compute Traffic Engineered Paths (TE Paths).

This document defines a YANG [RFC7950] data model for representing and manipulating TE Topologies. This model contains technology

agnostic TE Topology building blocks that can be augmented and used by other technology-specific TE Topology models.

### 1.1. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

The reader is assumed to be familiar with general body of work captured in currently available TE related RFCs. [RFC7926] serves as a good starting point for those who may be less familiar with Traffic Engineering related RFCs.

Some of the key terms used in this document are:

**TED:** The Traffic Engineering Database is a collection of all TE information about all TE nodes and TE links in a given network.

**TE-Topology:** The TE Topology is a schematic arrangement of TE nodes and TE links in a given TED. It forms the basis for a graph suitable for TE path computations.

**Native TE Topology:** Native TE Topology is a topology that is native to a given provider network. Native TE topology could be discovered via various routing protocols and/or subscribe/publish techniques. This is the topology on which path computational algorithms are run to compute TE Paths.

**Customized TE Topology:** Customized TE Topology is a custom topology that is produced by a provider for a given client. This topology typically makes abstractions on the provider's Native TE Topology, and is provided to the client. The client receives the Customized TE Topology, and merges it into the client's Native TE Topology. The client's path computational algorithms aren't typically run on the Customized TE Topology; they are run on the client's Native TE Topology after the merge.

### 1.2. Tree Structure

A simplified graphical representation of the data model is presented in Appendix A. of this document. The tree format defined in [RFC8340] is used for the YANG data model tree representation.

### 1.3. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

| Prefix   | YANG module           | Reference                     |
|----------|-----------------------|-------------------------------|
| yang     | ietf-yang-types       | [RFC6991]                     |
| inet     | ietf-inet-types       | [RFC6991]                     |
| nw       | ietf-network          | [RFC6991]                     |
| nt       | ietf-network-topology | [RFC8345]                     |
| te-types | ietf-te-types         | [I-D.ietf-teas-yang-te-types] |

Table 1: Prefixes and corresponding YANG modules

## 2. Characterizing TE Topologies

The data model proposed by this document takes the following characteristics of TE Topologies into account:

- TE Topology is an abstract control-plane representation of the data-plane topology. Hence attributes specific to the data-plane must make their way into the corresponding TE Topology modeling. The TE Topology comprises of dynamic auto-discovered data as well as fairly static data associated with data-plane nodes and links. The dynamic data may change frequently, such as unreserved bandwidth available on data-plane links. The static data rarely changes, such as layer network identification, switching and adaptation capabilities and limitations, fate sharing, and administrative colors. It is possible for a single TE Topology to encompass TE information at multiple switching layers.
- TE Topologies are protocol independent. Information about topological elements may be learnt via link-state protocols, but the topology can exist without being dependent on any particular protocol.
- TE Topology may not be congruent to the routing topology in a given TE System. The routing topology is constructed based on routing adjacencies. There isn't always a one-to-one association between a TE-link and a routing adjacency. For example, the presence of a TE link between a pair of nodes doesn't necessarily imply the existence of a routing-adjacency between these nodes. To

learn more, see [I-D.ietf-teas-te-topo-and-tunnel-modeling] and [I-D.ietf-teas-yang-l3-te-topo].

- Each TE Topological element has at least one information source associated with it. In some scenarios, there could be more than one information source associated with any given topological element.
- TE Topologies can be hierarchical. Each node and link of a given TE Topology can be associated with respective underlay topology. This means that each node and link of a given TE Topology can be associated with an independent stack of supporting TE Topologies.
- TE Topologies can be customized. TE topologies of a given network presented by the network provider to its client could be customized on per-client request basis. This customization could be performed by provider, by client or by provider/client negotiation. The relationship between a customized topology and provider's native topology could be captured as hierarchical (overlay-underlay), but otherwise the two topologies are decoupled from each other. A customized topology is presented to the client, while provider's native topology is known in its entirety to the provider itself.

### 3. Modeling Abstractions and Transformations

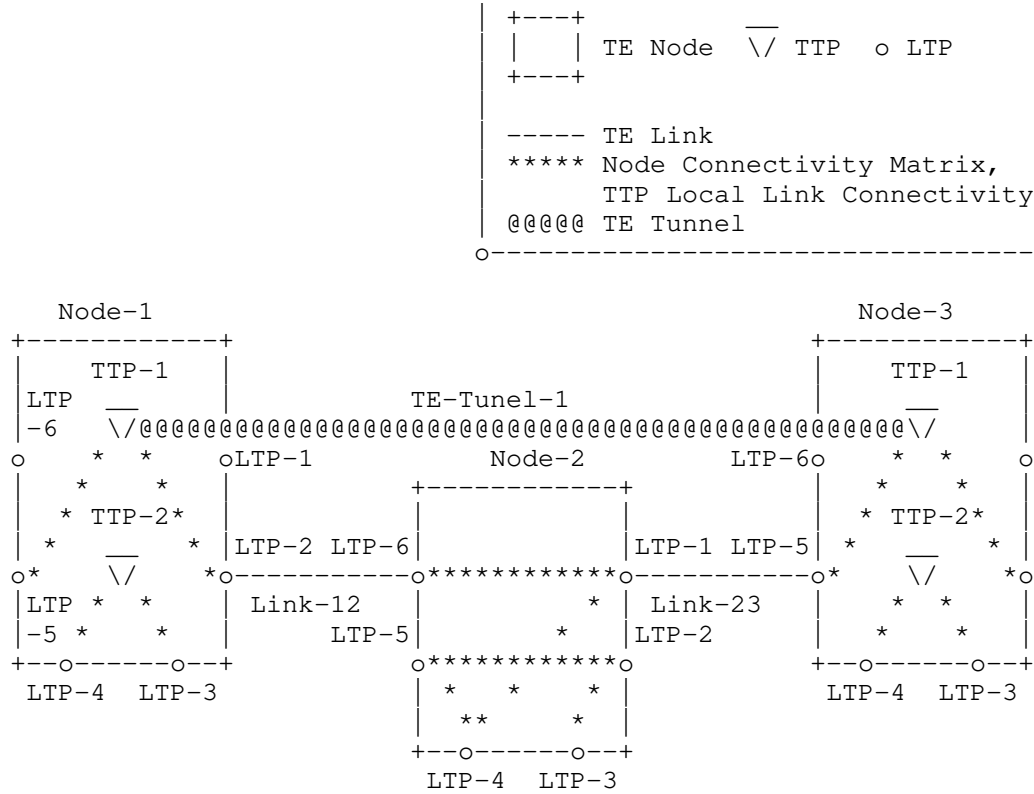


Figure 1: TE Topology Modeling Abstractions

#### 3.1. TE Topology

TE topology is a traffic engineering representation of one or more layers of network topologies. TE topology is comprised of TE nodes (TE graph vertices) interconnected via TE links (TE graph edges). A TE topology is mapped to a TE graph.

#### 3.2. TE Node

TE node is an element of a TE topology, presented as a vertex on TE graph. TE node represents one or several nodes, or a fraction of a node, which can be a switch or router that is physical or virtual. TE node belongs to and is fully defined in exactly one TE topology. TE node is assigned a unique ID within the TE topology scope. TE node attributes include information related to the data plane aspects of

the associated node(s) (e.g. connectivity matrix), as well as configuration data (such as TE node name). A given TE node can be reached on the TE graph over one of TE links terminated by the TE node.

Multi-layer TE nodes providing switching functions at multiple network layers are an example where a physical node can be decomposed into multiple logical TE nodes, which are fractions of the physical node. Some of these (logical) TE nodes may reside in the client layer TE topology while the remaining TE nodes belong to the server layer TE topology.

In Figure 1, Node-1, Node-2, and Node-3 are TE nodes.

### 3.3. TE Link

TE link is an element of a TE topology, presented as an edge on TE graph. The arrows on an edge indicate one or both directions of the TE link. When there are a pair of parallel links of opposite directions, an edge without arrows is also used. TE link represents one or several (physical) links or a fraction of a link. TE link belongs to and is fully defined in exactly one TE topology. TE link is assigned a unique ID within the TE topology scope. TE link attributes include parameters related to the data plane aspects of the associated link(s) (e.g. unreserved bandwidth, resource maps/pools, etc.), as well as the configuration data (such as remote node/link IDs, SRLGs, administrative colors, etc.). TE link is connected to TE node, terminating the TE link via exactly one TE link termination point (LTP).

In Figure 1, Link-12 and Link-23 are TE links.

### 3.4. Transitional TE Link for Multi-Layer Topologies

Networks are typically composed of multiple network layers where one or multiple signals in the client layer network can be multiplexed and encapsulated into a server layer signal [RFC5212] [G.805]. The server layer signal can be carried in the server layer network across multiple nodes until the server layer signal is terminated and the client layer signals reappear in the node that terminates the server layer signal. Examples of multi-layer networks are: IP over MPLS over Ethernet, low order Optical Data Unit-k (ODUk) signals multiplexed into a high order ODUL (l>k) carried over an Optical Channel (OCh) signal in an optical transport network as defined in [G.872] and [G.709].

TE links as defined in Section 3.3. can be used to represent links within a network layer. In case of a multi-layer network, TE nodes and TE links only allow representation of each network layer as a separate TE topology. Each of these single layer TE topologies would be isolated from their client and their server layer TE topology, if present. The highest and the lowest network layer in the hierarchy only have a single adjacent layer below or above, respectively. Multiplexing of client layer signals and encapsulating them into a server layer signal requires a function that is provided inside a node (typically realized in hardware). This function is also called layer transition.

One of the key requirements for path computation is to be able to calculate a path between two endpoints across a multi-layer network based on the TE topology representing this multi-layer network. This means that an additional TE construct is needed that represents potential layer transitions in the multi-layer TE-topology that connects the TE-topologies representing each separate network layer. The so-called transitional TE link is such a construct and it represents the layer transition function residing inside a node that is decomposed into multiple logical nodes that are represented as TE nodes (see also the transitional link definition in [G.8080] for the optical transport network). Hence, a transitional TE link connects a client layer node with a server layer node. A TE link as defined in 3.3. has LTPs of exactly the same kind on each link end whereas the transitional TE link has client layer LTPs on the client side of the transitional link and in most cases a single server layer LTP on the server side. It should be noted that transitional links are a helper construct in the multi-layer TE topology and they only exist as long as they are not in use, as they represent potential connectivity. When the server layer trail has been established between the server layer LTP of two transitional links in the server layer network, the resulting client layer link in the data plane will be represented as a normal TE link in the client layer topology. The transitional TE links will re-appear when the server layer trail has been torn down.

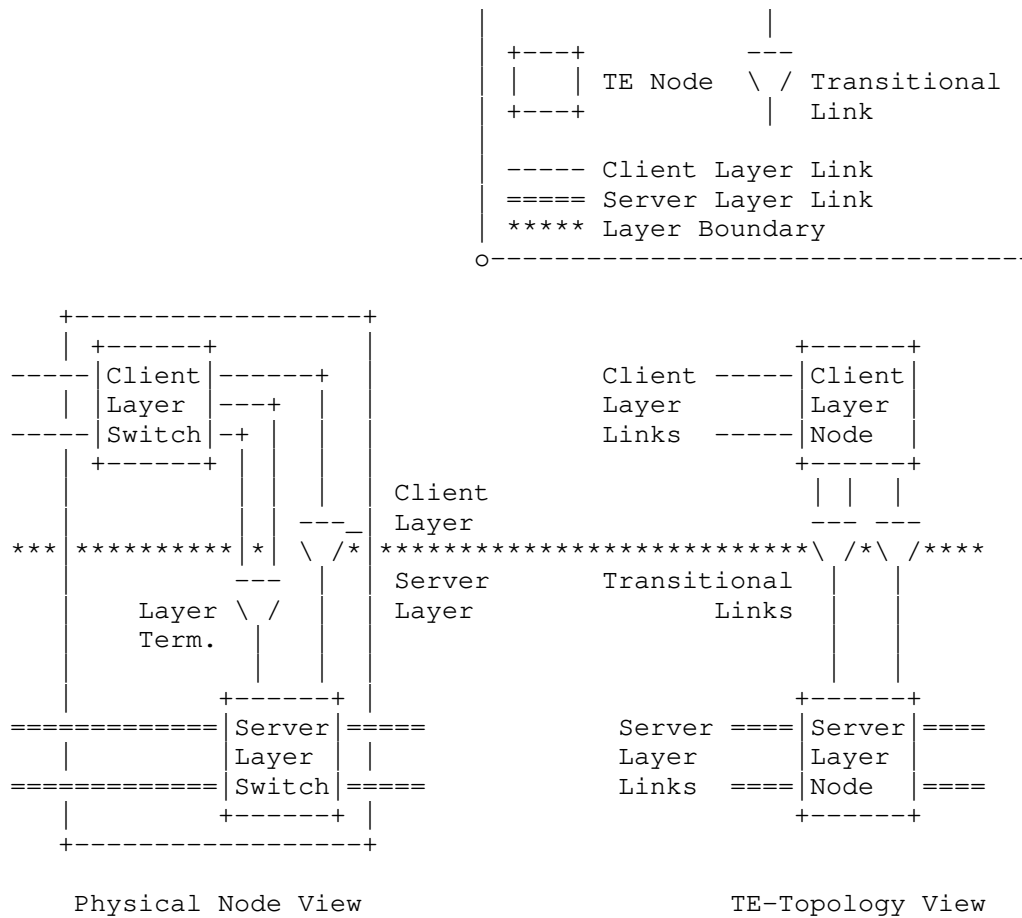


Figure 2: Modeling a Multi-Layer Node (Dual-Layer Example)

### 3.5. TE Link Termination Point (LTP)

TE link termination point (LTP) is a conceptual point of connection of a TE node to one of the TE links, terminated by the TE node. Cardinality between an LTP and the associated TE link is 1:0..1.

In Figure 1, Node-2 has six LTPs: LTP-1 to LTP-6.

### 3.6. TE Tunnel Termination Point (TTP)

TE tunnel termination point (TTP) is an element of TE topology representing one or several of potential transport service termination points (i.e. service client adaptation points such as



WDM/OCh transponder). TTP is associated with (hosted by) exactly one TE node. TTP is assigned a unique ID within the TE node scope. Depending on the TE node's internal constraints, a given TTP hosted by the TE node could be accessed via one, several or all TE links terminated by the TE node.

In Figure 1, Node-1 has two TTPs: TTP-1 and TTP-2.

### 3.7. TE Node Connectivity Matrix

TE node connectivity matrix is a TE node's attribute describing the TE node's switching limitations in a form of valid switching combinations of the TE node's LTPs (see below). From the point of view of a potential TE path arriving at the TE node at a given inbound LTP, the node's connectivity matrix describes valid (permissible) outbound LTPs for the TE path to leave the TE node from.

In Figure 1, the connectivity matrix on Node-2 is:  
{<LTP-6, LTP-1>, <LTP-5, LTP-2>, <LTP-5, LTP-4>, <LTP-4, LTP-1>, <LTP-3, LTP-2>}

### 3.8. TTP Local Link Connectivity List (LLCL)

TTP Local Link Connectivity List (LLCL) is a List of TE links terminated by the TTP hosting TE node (i.e. list of the TE link LTPs), which the TTP could be connected to. From the point of view of a potential TE path, LLCL provides a list of valid TE links the TE path needs to start/stop on for the connection, taking the TE path, to be successfully terminated on the TTP in question.

In Figure 1, the LLCL on Node-1 is:  
{<TTP-1, LTP-5>, <TTP-1, LTP-2>, <TTP-2, LTP-3>, <TTP-2, LTP4>}

### 3.9. TE Path

TE path is an ordered list of TE links and/or TE nodes on the TE topology graph, inter-connecting a pair of TTPs to be taken by a potential connection. TE paths, for example, could be a product of successful path computation performed for a given transport service.

In Figure 1, the TE Path for TE-Tunnel-1 is:  
{Node-1:TTP-1, Link-12, Node-2, Link-23, Node-3:TTP1}

## 3.10. TE Inter-Layer Lock

TE inter-layer lock is a modeling concept describing client-server layer adaptation relationships and hence important for the multi-layer traffic engineering. It is an association of M client layer LTPs and N server layer TTPs, within which data arriving at any of the client layer LTPs could be adopted onto any of the server layer TTPs. TE inter-layer lock is identified by inter-layer lock ID, which is unique across all TE topologies provided by the same provider. The client layer LTPs and the server layer TTPs associated within a given TE inter-layer lock are annotated with the same inter-layer lock ID attribute.

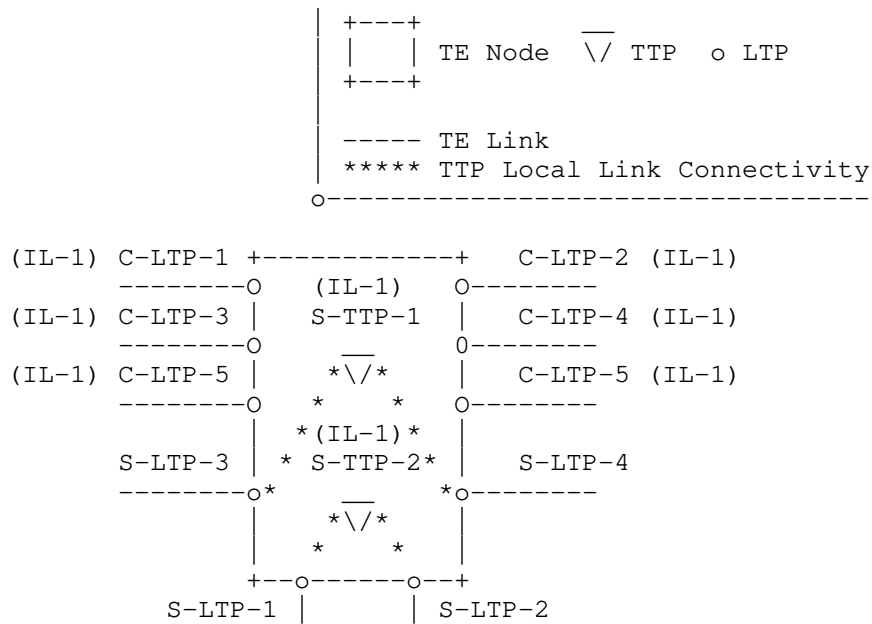


Figure 3: TE Inter-Layer Lock ID Associations

On the picture above a TE inter-layer lock with IL\_1 ID associates 6 client layer LTPs (C-LTP-1 - C-LTP-6) with two server layer TTPs (S-TTP-1 and S-TTP-2). They all have the same attribute - TE inter-layer lock ID: IL-1, which is the only thing that indicates the association. A given LTP may have 0, 1 or more inter-layer lock IDs. In the latter case this means that the data arriving at the LTP may be adopted onto any of TTPs associated with all specified inter-layer locks. For example, C-LTP-1 could have two inter-layer lock IDs - IL-1 and IL-2. This would mean that C-LTP-1 for adaptation purposes could use not just TTPs associated with inter-layer lock IL-1 (i.e.

S-TTP-1 and S-TTP-2 on the picture), but any of TTPs associated with inter-layer lock IL-2 as well. Likewise, a given TTP may have one or more inter-layer lock IDs, meaning that it can offer the adaptation service to any of client layer LTPs with inter-layer lock ID matching one of its own. Additionally, each TTP has an attribute - Unreserved Adaptation Bandwidth, which announces its remaining adaptation resources sharable between all potential client LTPs.

LTPs and TTPs associated within the same TE inter-layer lock may be hosted by the same (hybrid, multi-layer) TE node or multiple TE nodes located in the same or separate TE topologies. The latter is especially important since TE topologies of different layer networks could be modeled by separate augmentations of the basic (common to all layers) TE topology model.

### 3.11. Underlay TE topology

Underlay TE topology is a TE topology that serves as a base for constructing of overlay TE topologies

### 3.12. Overlay TE topology

Overlay TE topology is a TE topology constructed based on one or more underlay TE topologies. Each TE node of the overlay TE topology represents an arbitrary segment of an underlay TE topology; each TE link of the overlay TE topology represents an arbitrary TE path in one of the underlay TE topologies. The overlay TE topology and the supporting underlay TE topologies may represent distinct layer networks (e.g. OTN/ODUk and WDM/OCh respectively) or the same layer network.

### 3.13. Abstract TE topology

Abstract TE topology is a topology that contains abstract topological elements (nodes, links, tunnel termination points). Abstract TE topology is an overlay TE topology created by a topology provider and customized for a topology provider's client based on one or more of the provider's native TE topologies (underlay TE topologies), the provider's policies and the client's preferences. For example, a first level topology provider (such as Domain Controller) can create an abstract TE topology for its client (e.g. Multi-Domain Service Coordinator) based on the provider's one or more native TE topologies, local policies/profiles and the client's TE topology configuration requests

Figure 4 shows an example of abstract TE topology.

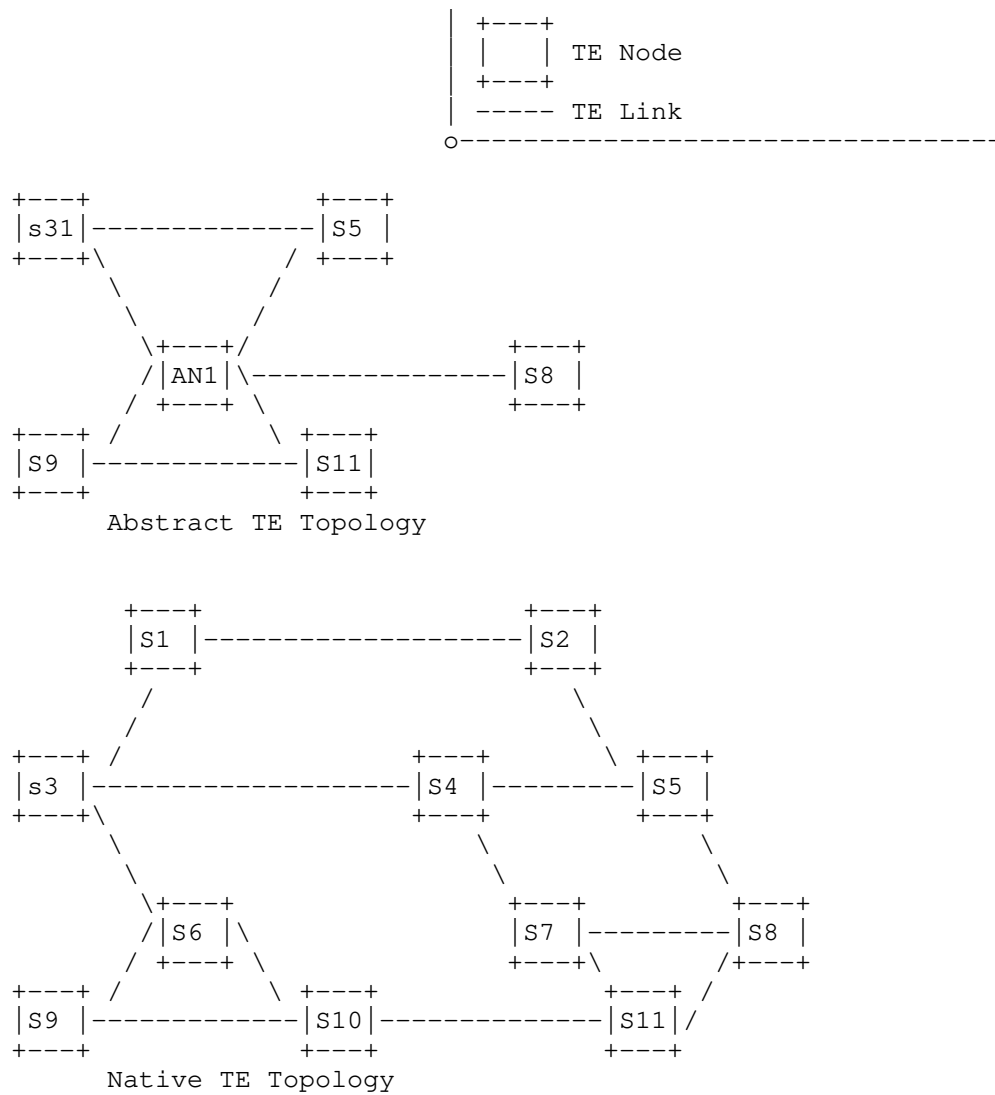


Figure 4: Abstract TE Topology

#### 4. Model Applicability

##### 4.1. Native TE Topologies

The model discussed in this draft can be used to represent and retrieve native TE topologies on a given TE system.

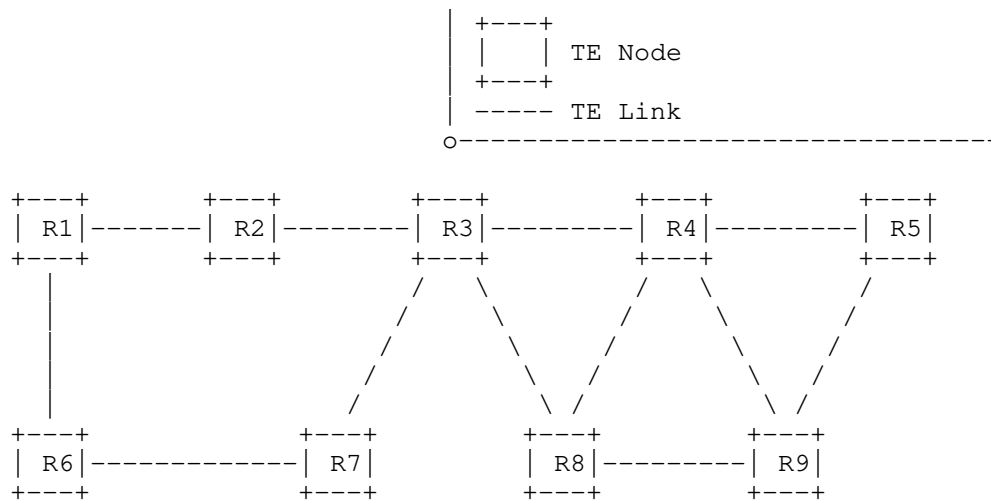


Figure 5a: Example Network Topology

Consider the network topology depicted in Figure 5a. R1 .. R9 are nodes representing routers. An implementation MAY choose to construct a native TE Topology using all nodes and links present in the given TED as depicted in Figure 5b. The data model proposed in this document can be used to retrieve/represent this TE topology.

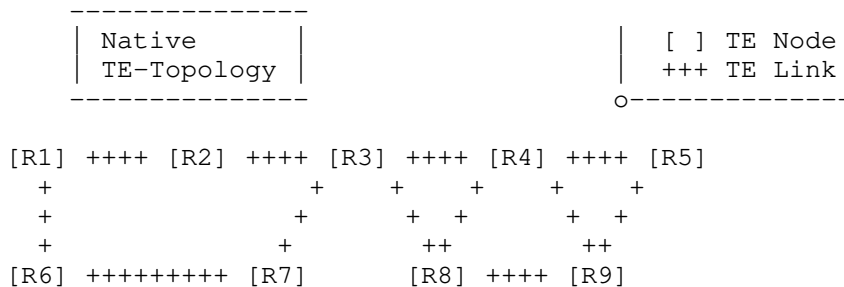


Figure 5b: Native TE Topology as seen on Node R3

Consider the case of the topology being split in a way that some nodes participate in OSPF-TE while others participate in ISIS-TE (Figure 6a). An implementation MAY choose to construct separate TE Topologies based on the information source. The native TE Topologies constructed using only nodes and links that were learnt via a specific information source are depicted in Figure 6b. The data model proposed in this document can be used to retrieve/represent these TE topologies.

Similarly, the data model can be used to represent/retrieve a TE Topology that is constructed using only nodes and links that belong to a particular technology layer. The data model is flexible enough to retrieve and represent many such native TE Topologies.

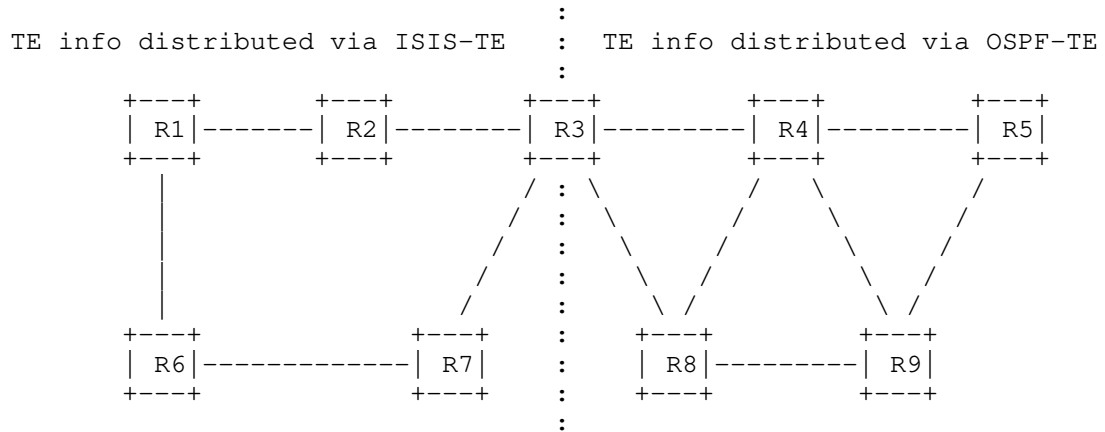


Figure 6a: Example Network Topology

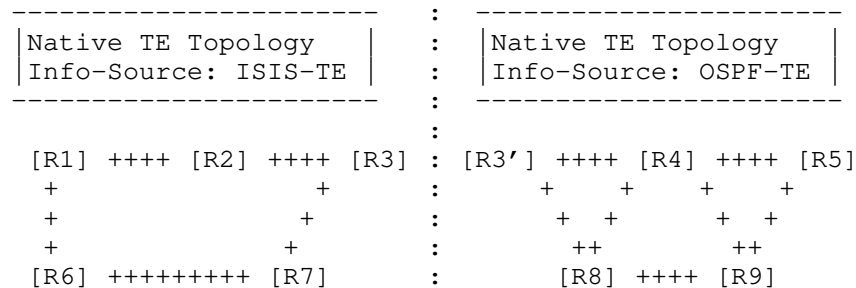


Figure 6b: Native TE Topologies as seen on Node R3

## 4.2. Customized TE Topologies

Customized TE topology is a topology that was modified by the provider to honor a particular client's requirements or preferences. The model discussed in this draft can be used to represent, retrieve and manipulate customized TE Topologies. The model allows the provider to present the network in abstract TE Terms on a per client

basis. These customized topologies contain sufficient information for the path computing client to select paths according to its policies.

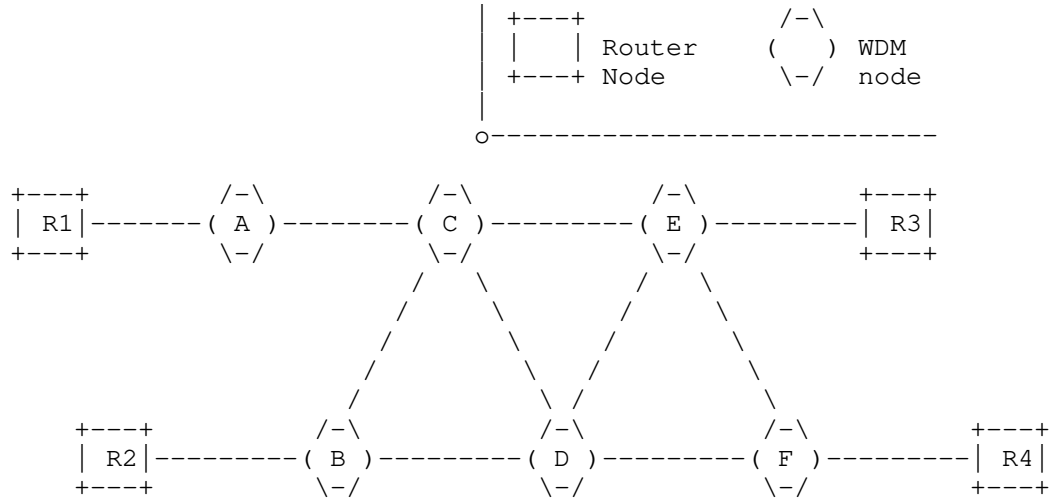


Figure 7: Example packet optical topology

Consider the network topology depicted in Figure 7. This is a typical packet optical transport deployment scenario where the WDM layer network domain serves as a Server Network Domain providing transport connectivity to the packet layer network Domain (Client Network Domain). Nodes R1, R2, R3 and R4 are IP routers that are connected to an Optical WDM transport network. A, B, C, D, E and F are WDM nodes that constitute the Server Network Domain.

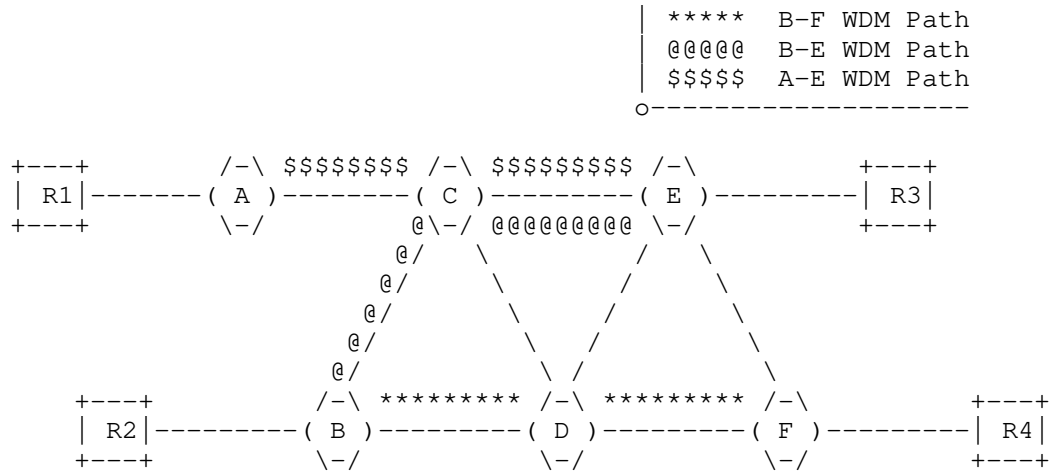


Figure 8a: Paths within the provider domain

```

+++++++ [A] ++++++ [E] ++++++
 ++++++
 ++++++
 ++++++
 ++++++
 ++++++
+++++++ [B] ++++++ [F] ++++++

```

Figure 8b: Customized TE Topology provided to the Client

The goal here is to augment the Client TE Topology with a customized TE Topology provided by the WDM network. Given the availability of the paths A-E, B-F and B-E (Figure 8a), a customized TE Topology as depicted in Figure 8b is provided to the Client. This customized TE Topology is merged with the Client's Native TE Topology and the resulting topology is depicted in Figure 8c.

```

[R1] ++++++ [A] ++++++ [E] ++++++ [R3]
 ++++++
 ++++++
 ++++++
 ++++++
 ++++++
[R2] ++++++ [B] ++++++ [F] ++++++ [R4]

```

Figure 8c: Customized TE Topology merged with the Client's Native TE Topology

The data model proposed in this document can be used to retrieve/represent/manipulate the customized TE Topology depicted in Figure 8b.

A customized TE topology is not necessarily an abstract TE topology. The provider may produce, for example, an abstract TE topology of certain type (e.g. single-abstract-node-with-connectivity-matrix topology, a border-nodes-connected-via-mesh-of-abstract-links topology, etc.) and expose it to all/some clients in expectation that the clients will use it without customization. On the other hand, a client may request a customized version of the provider's native TE topology (e.g. by requesting removal of TE links



which belong to certain layers, are too slow, not protected and/or have a certain affinity). Note that the resulting TE topology will not be abstract (because it will not contain abstract elements), but customized (modified upon client's instructions).

The client ID field in the TE topology identifier (Section 5.4. ) indicates which client the TE topology is customized for. Although an authorized client MAY receive a TE topology with the client ID field matching some other client, the client can customize only TE topologies with the client ID field either 0 or matching the ID of the client in question. If the client starts reconfiguration of a topology its client ID will be automatically set in the topology ID field for all future configurations and updates wrt. the topology in question.

The provider MAY tell the client that a given TE topology cannot be re-negotiated, by setting its own (provider's) ID in the client ID field of the topology ID.

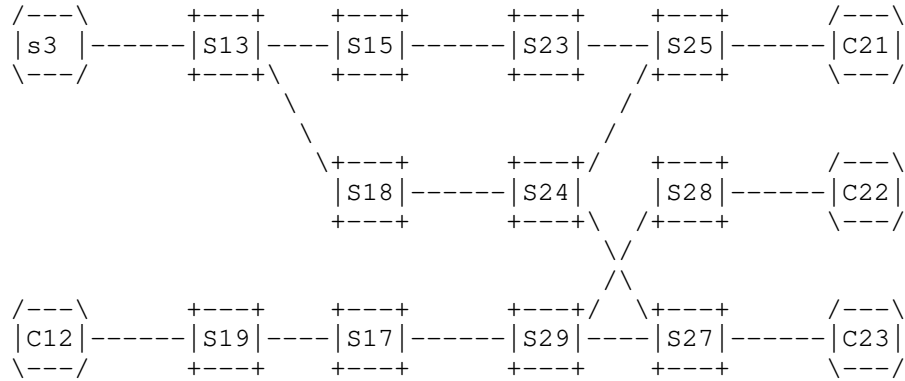
Even though this data model allows to access TE topology information across clients, implementations MAY restrict access for particular clients to particular data fields. The Network Configuration Access Control Model (NACM) [RFC8341] provides such a mechanism.

#### 4.3. Merging TE Topologies Provided by Multiple Providers

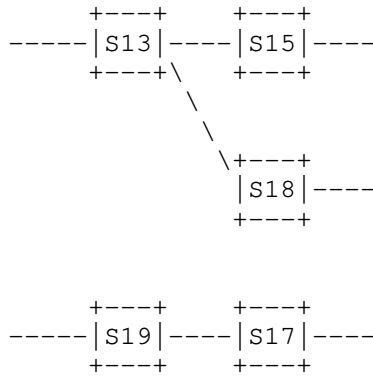
A client may receive TE topologies provided by multiple providers, each of which managing a separate domain of multi-domain network. In order to make use of said topologies, the client is expected to merge the provided TE topologies into one or more client's native TE topologies, each of which homogeneously representing the multi-domain network. This makes it possible for the client to select end-to-end TE paths for its services traversing multiple domains.

In particular, the process of merging TE topologies includes:

- Identifying neighboring domains and locking their topologies horizontally by connecting their inter-domain open-ended TE links;
- Renaming TE node, link, and SRLG IDs to ones allocated from a separate name space; this is necessary because all TE topologies are considered to be, generally speaking, independent with a possibility of clashes among TE node, link or SRLG IDs;
- Locking, vertically, TE topologies associated with different layer networks, according to provided topology inter-layer locks; this is to facilitate inter-layer path computations across multiple TE topologies provided by the same topology provider.



Domain 1 TE Topology



Domain 2 TE Topology

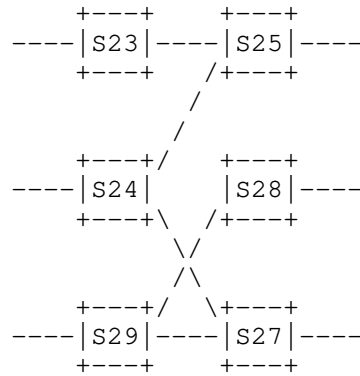


Figure 9: Merging Domain TE Topologies

Figure 9 illustrates the process of merging, by the client, of TE topologies provided by the client's providers. In the Figure, each of the two providers caters to the client (abstract or native) TE topology, describing the network domain under the respective provider's control. The client, by consulting the attributes of the inter-domain TE links - such as inter-domain plug IDs or remote TE node/link IDs (as defined by the TE Topology model) - is able to determine that:

- a) the two domains are adjacent and are inter-connected via three inter-domain TE links, and;

- b) each domain is connected to a separate customer site, connecting the left domain in the Figure to customer devices C-11 and C-12, and the right domain to customer devices C-21, C-22 and C-23.

Therefore, the client inter-connects the open-ended TE links, as shown on the upper part of the Figure.

As mentioned, one way to inter-connect the open-ended inter-domain TE links of neighboring domains is to mandate the providers to specify remote nodeID/linkID attribute in the provided inter-domain TE links. This, however, may prove to be not flexible. For example, the providers may not know the respective remote nodeIDs/ linkIDs. More importantly, this option does not allow for the client to mix-n-match multiple (more than one) topologies catered by the same providers (see below). Another, more flexible, option to resolve the open-ended inter-domain TE links is by annotating them with the inter-domain plug ID attribute. Inter-domain plug ID is a network-wide unique number that identifies on the network a connectivity supporting a given inter-domain TE link. Instead of specifying remote node ID/link ID, an inter-domain TE link may provide a non-zero inter-domain plug ID. It is expected that two neighboring domain TE topologies (provided by separate providers) will have each at least one open-ended inter-domain TE link with an inter-domain plug ID matching to one provided by its neighbor. For example, the inter-domain TE link originating from node S15 of the Domain 1 TE topology (Figure 9) and the inter-domain TE link coming from node S23 of Domain 2 TE topology may specify matching inter-domain plug ID (e.g. 175344). This allows for the client to identify adjacent nodes in the separate neighboring TE topologies and resolve the inter-domain TE links connecting them regardless of their respective nodeIDs/linkIDs (which, as mentioned, could be allocated from independent name spaces). Inter-domain plug IDs may be assigned and managed by a central network authority. Alternatively, inter-domain plug IDs could be dynamically auto-discovered (e.g. via LMP protocol).

Furthermore, the client renames the TE nodes, links and SRLGs offered in the abstract TE topologies by assigning to them IDs allocated from a separate name space managed by the client. Such renaming is necessary, because the two abstract TE topologies may have their own name spaces, generally speaking, independent one from another; hence, ID overlaps/clashes are possible. For example, both TE topologies have TE nodes named S7, which, after renaming, appear in the merged TE topology as S17 and S27, respectively.

Once the merging process is complete, the client can use the merged TE topology for path computations across both domains, for example, to compute a TE path connecting C-11 to C-23.

#### 4.4. Dealing with Multiple Abstract TE Topologies Provided by the Same Provider

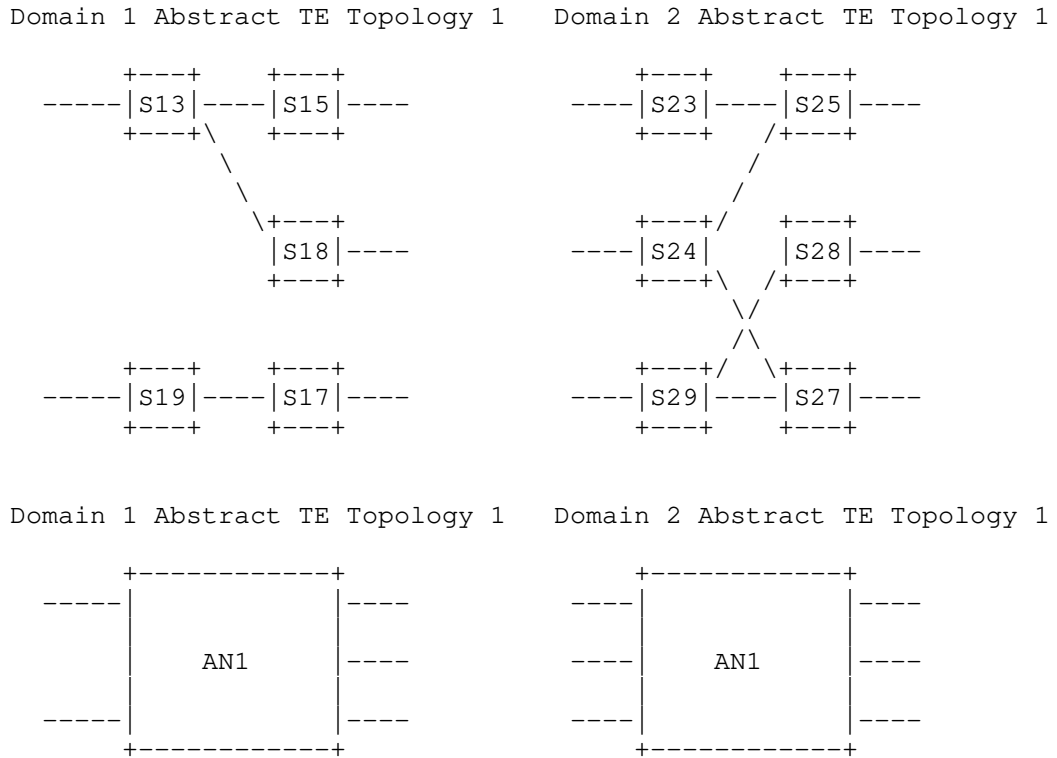


Figure 10: Merging Domain TE Topologies

Based on local configuration, templates and/or policies pushed by the client, a given provider may expose more than one abstract TE topology to the client. For example, one abstract TE topology could be optimized based on a lowest-cost criterion, while another one could be based on best possible delay metrics, while yet another one could be based on maximum bandwidth availability for the client services. Furthermore, the client may request all or some providers to expose additional abstract TE topologies, possibly of a different type and/or optimized differently, as compared to already-provided TE topologies. In any case, the client should be prepared for a provider to offer to the client more than one abstract TE topology.

It should be up to the client (based on the client's local configuration and/or policies conveyed to the client by the client's

clients) to decide how to mix-and-match multiple abstract TE topologies provided by each or some of the providers, as well as how to merge them into the client's native TE topologies. The client also decides how many such merged TE topologies it needs to produce and maintain. For example, in addition to the merged TE topology depicted in the upper part of Figure 9, the client may merge the abstract TE topologies received from the two providers, as shown in Figure 10, into the client's additional native TE topologies, as shown in Figure 11.

Note that allowing for the client mix-n-matching of multiple TE topologies assumes that inter-domain plug IDs (rather than remote nodeID/linkID) option is used for identifying neighboring domains and inter-domain TE link resolution.

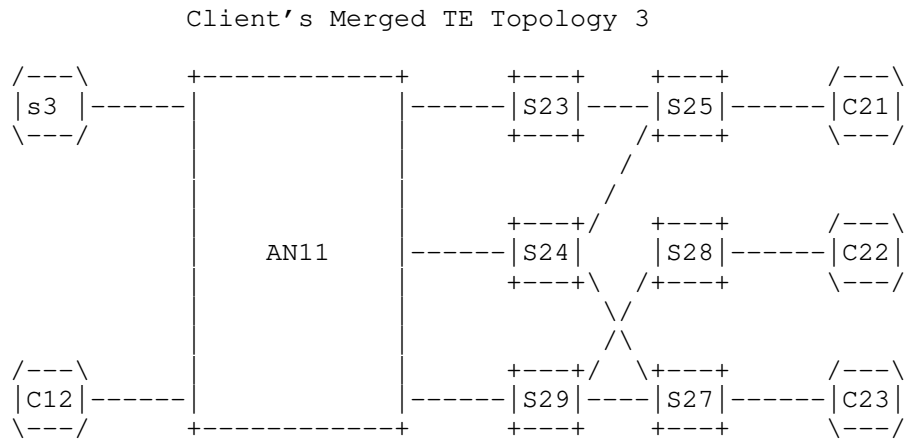
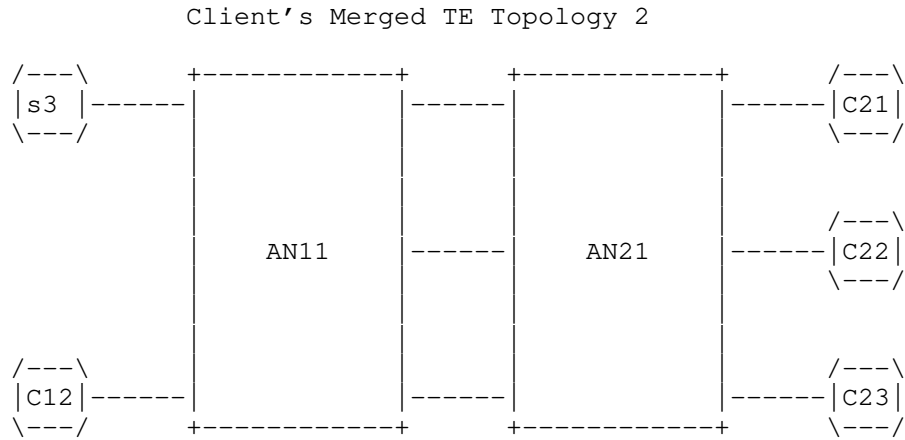


Figure 11: Multiple Native (Merged) Client's TE Topologies

It is important to note that each of the three native (merged) TE topologies could be used by the client for computing TE paths for any of the multi-domain services. The choice as to which topology to use for a given service depends on the service parameters/requirements and the topology's style, optimization criteria and the level of details.

## 5. Modeling Considerations

### 5.1. Network topology building blocks

The network topology building blocks are discussed in [RFC8345]. The TE Topology model proposed in this document augments and uses the `ietf-network-topology` module defined in [RFC8345].

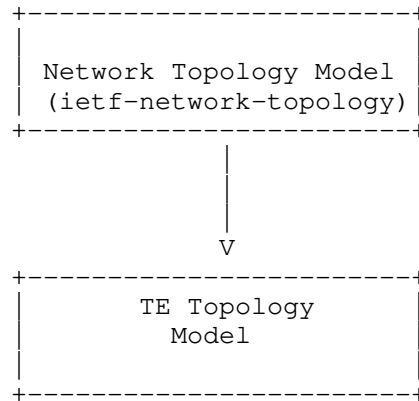


Figure 12: Augmenting the Network Topology Model

### 5.2. Technology agnostic TE Topology model

The TE Topology model proposed in this document is meant to be network technology agnostic. Other technology specific TE Topology models can augment and use the building blocks provided by the proposed model.

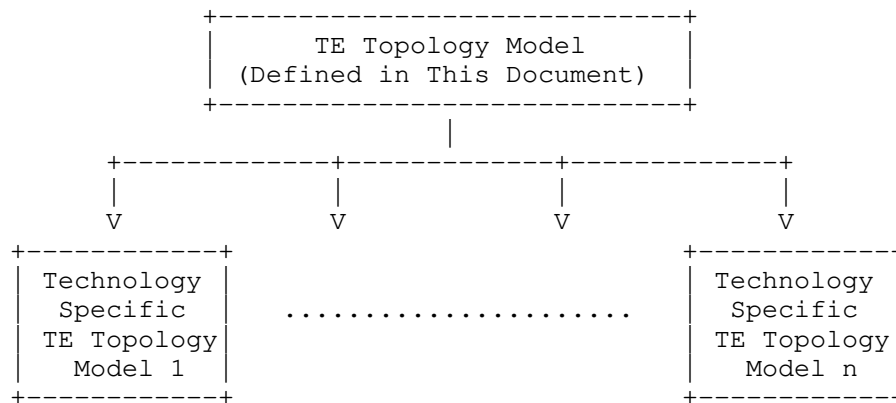


Figure 13: Augmenting the Technology agnostic TE Topology model

### 5.3. Model Structure

The high-level model structure proposed by this document is as shown below:

```

module: ietf-te-topology
augment /nw:networks/nw:network/nw:network-types:
 +--rw te-topology!

augment /nw:networks:
 +--rw te!
 +--rw templates
 +--rw node-template* [name] {template}?
 |
 +--rw link-template* [name] {template}?

augment /nw:networks/nw:network:
 +--rw te-topology-identifier
 | +--rw provider-id? te-global-id
 | +--rw client-id? te-global-id
 | +--rw topology-id? te-topology-id
 +--rw te!
 |

augment /nw:networks/nw:network/nw:node:
 +--rw te-node-id? te-types:te-node-id
 +--rw te!
 |
 +--rw tunnel-termination-point* [tunnel-tp-id]

```



```

 +--rw tunnel-tp-id binary
 |
 +--rw supporting-tunnel-termination-point* [node-ref tunnel-
tp-ref]
 |

```

```

augment /nw:networks/nw:network/nt:link:
 +--rw te!
 |

```

```

augment /nw:networks/nw:network/nw:node/nt:termination-point:
 +--rw te-tp-id? te-types:te-tp-id
 +--rw te!
 |

```

#### 5.4. Topology Identifiers

The TE-Topology is uniquely identified by a key that has 3 constituents - topology-id, provider-id and client-id. The combination of provider-id and topology-id uniquely identifies a native TE Topology on a given provider. The client-id is used only when Customized TE Topologies come into play; a value of "0" is used as the client-id for native TE Topologies.

```

augment /nw:networks/nw:network:
 +--rw te-topology-identifier
 | +--rw provider-id? te-global-id
 | +--rw client-id? te-global-id
 | +--rw topology-id? te-topology-id
 +--rw te!
 |

```

#### 5.5. Generic TE Link Attributes

The model covers the definitions for generic TE Link attributes - bandwidth, admin groups, SRLGs, switching capabilities, TE metric extensions etc.

```

+--rw te-link-attributes

 +--rw admin-status? te-admin-status
 |
 +--rw link-index? uint64
 +--rw administrative-group? te-types:admin-groups
 +--rw link-protection-type? enumeration
 +--rw max-link-bandwidth? te-bandwidth

```

```

+--rw max-resv-link-bandwidth? te-bandwidth
+--rw unreserved-bandwidth* [priority]
|
+--rw te-default-metric? uint32
|
+--rw te-srlgs
+--rw te-nsrlgs {nsrlg}?

```

## 5.6. Generic TE Node Attributes

The model covers the definitions for generic TE Node attributes.

The definition of a generic connectivity matrix is shown below:

```

+--rw te-node-attributes
|
| +--rw connectivity-matrices
| |
| | +--rw connectivity-matrix* [id]
| | | +--rw id uint32
| | | +--rw from
| | | | +--rw tp-ref? leafref
| | | | +--rw label-restrictions
| | | +--rw to
| | | | +--rw tp-ref? leafref
| | | | +--rw label-restrictions
| | | +--rw is-allowed? boolean
| |
| | +--rw underlay! {te-topology-hierarchy}?
| |
| | +--rw path-constraints
| |
| | +--rw optimizations
| |
| | +--rw path-properties
| |
|

```

The definition of a TTP Local Link Connectivity List is shown below:

```

+--rw tunnel-termination-point* [tunnel-tp-id]
| +--rw tunnel-tp-id binary
| +--rw admin-status? te-types:te-admin-status
| +--rw name? string
| +--rw switching-capability? identityref
| +--rw encoding? identityref
| +--rw inter-layer-lock-id* uint32

```

```

 +--rw protection-type? Identityref
 +--rw client-layer-adaptation

 +--rw local-link-connectivities

 | +--rw local-link-connectivity* [link-tp-ref]
 | | +--rw link-tp-ref leafref
 | | +--rw label-restrictions
 |
 | | +--rw is-allowed? boolean
 | | +--rw underlay {te-topology-hierarchy}?
 |
 | | +--rw path-constraints
 |
 | | +--rw optimizations
 |
 | | +--ro path-properties
 |
 +--rw supporting-tunnel-termination-point* [node-ref tunnel-tp-
ref]
 +--rw node-ref inet:uri
 +--rw tunnel-tp-ref binary

```

The attributes directly under container connectivity-matrices are the default attributes for all connectivity-matrix entries when the per entry corresponding attribute is not specified. When a per entry attribute is specified, it overrides the corresponding attribute directly under the container connectivity-matrices. The same rule applies to the attributes directly under container local-link-connectivities.

Each TTP (Tunnel Termination Point) MAY be supported by one or more supporting TTPs. If the TE node hosting the TTP in question refers to a supporting TE node, then the supporting TTPs are hosted by the supporting TE node. If the TE node refers to an underlay TE topology, the supporting TTPs are hosted by one or more specified TE nodes of the underlay TE topology.

### 5.7. TED Information Sources

The model allows each TE topological element to have multiple TE information sources (OSPF-TE, ISIS-TE, BGP-LS, User-Configured, System-Processed, Other). Each information source is associated with a credibility preference to indicate precedence. In scenarios where a customized TE Topology is merged into a Client's native TE Topology, the merged topological elements would point to the corresponding customized TE Topology as its information source.

```

augment /nw:networks/nw:network/nw:node:
 +--rw te!

 +--ro information-source? te-info-source
 +--ro information-source-instance? string
 +--ro information-source-state
 |
 +--ro credibility-preference? uint16
 +--ro logical-network-element? string
 +--ro network-instance? string
 +--ro topology
 |
 +--ro node-ref? leafref
 +--ro network-ref? leafref
 +--ro information-source-entry*
 |
 [information-source information-source-instance]
 +--ro information-source te-info-source
 +--ro information-source-instance string

augment /nw:networks/nw:network/nt:link:
 +--rw te!

 +--ro information-source? te-info-source
 +--ro information-source-instance? string
 +--ro information-source-state
 |
 +--ro credibility-preference? uint16
 +--ro logical-network-element? string
 +--ro network-instance? string
 +--ro topology
 |
 +--ro link-ref? leafref
 +--ro network-ref? leafref
 +--ro information-source-entry*
 |
 [information-source information-source-instance]
 +--ro information-source te-info-source
 +--ro information-source-instance string


```

## 5.8. Overlay/Underlay Relationship

The model captures overlay and underlay relationship for TE nodes/links. For example - in networks where multiple TE Topologies are built hierarchically, this model allows the user to start from a specific topological element in the top most topology and traverse all the way down to the supporting topological elements in the bottom most topology.

This relationship is captured via the "underlay-topology" field for the node and via the "underlay" field for the link. The use of these

fields is optional and this functionality is tagged as a "feature" ("te-topology-hierarchy").

```
augment /nw:networks/nw:network/nw:node:
 +--rw te-node-id? te-types:te-node-id
 +--rw te!
 +--rw te-node-template* leafref {template}?
 +--rw te-node-attributes
 |
 | +--rw underlay-topology {te-topology-hierarchy}?
 | +--rw network-ref? leafref
 |
 +--rw te-link-attributes
 |
 | +--rw underlay {te-topology-hierarchy}?
 | +--rw enabled? boolean
 | +--rw primary-path
 | | +--rw network-ref? leafref
 | |
 | +--rw backup-path* [index]
 | | +--rw index uint32
 | | +--rw network-ref? leafref
 | |
 | +--rw protection-type? identityref
 | +--rw tunnel-termination-points
 | | +--rw source? binary
 | | +--rw destination? binary
 | +--rw tunnels
 | |
 | |
```

## 5.9. Templates

The data model provides the users with the ability to define templates and apply them to link and node configurations. The use of "template" configuration is optional and this functionality is tagged as a "feature" ("template").

```
augment /nw:networks/nw:network/nw:node:
 +--rw te-node-id? te-types:te-node-id
 +--rw te!
 +--rw te-node-template*
 | -> ../../../../te/templates/node-template/name
 | {template}?
```

```

augment /nw:networks/nw:network/nt:link:
 +--rw te!
 +--rw te-link-template*
 | -> ../../../../te/templates/link-template/name
 | {template}?

augment /nw:networks:
 +--rw te!
 +--rw templates
 +--rw node-template* [name] {template}?
 +--rw name
 | te-types:te-template-name
 +--rw priority? uint16
 +--rw reference-change-policy? enumeration
 +--rw te-node-attributes

 +--rw link-template* [name] {template}?
 +--rw name
 | te-types:te-template-name
 +--rw priority? uint16
 +--rw reference-change-policy? enumeration
 +--rw te-link-attributes


```

Multiple templates can be specified to a configuration element. When two or more templates specify values for the same configuration field, the value from the template with the highest priority is used. The range of the priority is from 0 to 65535, with a lower number indicating a higher priority. The reference-change-policy specifies the action that needs to be taken when the template changes on a configuration element that has a reference to this template. The choices of action include taking no action, rejecting the change to the template and applying the change to the corresponding configuration.

#### 5.10. Scheduling Parameters

The model allows time scheduling parameters to be specified for each topological element or for the topology as a whole. These parameters allow the provider to present different topological views to the client at different time slots. The use of "scheduling parameters" is optional.

The YANG data model for configuration scheduling is defined in [I-D.liu-netmod-yang-schedule], which allows specifying configuration schedules without altering this data model.

### 5.11. Notifications

Notifications are a key component of any topology data model.

[I-D.ietf-netconf-subscribed-notifications] and [I-D.ietf-netconf-yang-push] define a subscription and push mechanism for YANG datastores. This mechanism currently allows the user to:

- Subscribe notifications on a per client basis
- Specify subtree filters or xpath filters so that only interested contents will be sent.
- Specify either periodic or on-demand notifications.

### 6. Guidance for Writing Technology Specific TE Topology Augmentations

The TE topology model defined in this document is technology agnostic as it defines concepts, abstractions and attributes that are common across multiple network technologies. It is envisioned that this base model will be widely used when defining technology specific TE topology models for various layer networks.

[I-D.ietf-ccamp-wson-yang], [I-D.ietf-ccamp-otn-topo-yang], and [I-D.ietf-teas-yang-l3-te-topo] are some examples of technology specific TE Topology models. Writers of such models are encouraged to augment the basic TE topology model's containers, such as TE Topology, TE Node, TE Link, Link Termination Point (LTP), Tunnel Termination Point (TTP), Bandwidth and Label with the layer specific attributes instead of defining new containers.

Consider the following technology specific example-topology model:

```
module: example-topology
 augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
 +--rw example-topology!
 augment /nw:networks/nw:network/tet:te:
 +--rw attributes
 +--rw attribute-1? uint8
 augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes:
 +--rw attributes
 +--rw attribute-2? uint8
 augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices:
 +--rw attributes
 +--rw attribute-3? uint8
 augment /nw:networks/nw:network/nw:node/tet:te
```

```

 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix:
 +--rw attributes
 +--rw attribute-3? uint8
 augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point:
 +--rw attributes
 +--rw attribute-4? uint8
 augment /nw:networks/nw:network/nw:node/nt:termination-point
 /tet:te:
 +--rw attributes
 +--rw attribute-5? uint8
 augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes:
 +--rw attributes
 +--rw attribute-6? uint8

```

The technology specific TE bandwidth for this example topology can be specified using the following augment statements:

```

 augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes
 /tet:interface-switching-capability/tet:max-lsp-bandwidth
 /tet:te-bandwidth/tet:technology:
 +--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
 augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes/tet:max-link-bandwidth
 /tet:te-bandwidth/tet:technology:
 +--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
 augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes/tet:max-resv-link-bandwidth
 /tet:te-bandwidth/tet:technology:
 +--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
 augment /nw:networks/tet:te/tet:templates/tet:link-template

```



```

 /tet:te-link-attributes/tet:unreserved-bandwidth
 /tet:te-bandwidth/tet:technology:
+--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:path-constraints/tet:te-bandwidth/tet:technology:
+--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:path-constraints
 /tet:te-bandwidth/tet:technology:
+--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:path-constraints/tet:te-bandwidth/tet:technology:
+--:(example)
 +--ro example
 +--ro bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:path-constraints
 /tet:te-bandwidth/tet:technology:
+--:(example)
 +--ro example
 +--ro bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point/tet:client-layer-adaptation
 /tet:switching-capability/tet:te-bandwidth
 /tet:technology:
+--:(example)
 +--rw example
 +--rw bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:path-constraints

```

```

 /tet:te-bandwidth/tet:technology:
+---: (example)
+---rw example
+---rw bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:path-constraints
 /tet:te-bandwidth/tet:technology:
+---: (example)
+---rw example
+---rw bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes
 /tet:interface-switching-capability/tet:max-lsp-bandwidth
 /tet:te-bandwidth/tet:technology:
+---: (example)
+---rw example
+---rw bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:max-link-bandwidth
 /tet:te-bandwidth/tet:technology:
+---: (example)
+---rw example
+---rw bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:max-resv-link-bandwidth
 /tet:te-bandwidth/tet:technology:
+---: (example)
+---rw example
+---rw bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry
 /tet:interface-switching-capability/tet:max-lsp-bandwidth
 /tet:te-bandwidth/tet:technology:
+---: (example)
+---ro example
+---ro bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry/tet:max-link-bandwidth
 /tet:te-bandwidth/tet:technology:

```

```

 +---:(example)
 +---ro example
 +---ro bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry/tet:max-resv-link-bandwidth
 /tet:te-bandwidth/tet:technology:
 +---:(example)
 +---ro example
 +---ro bandwidth-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry/tet:unreserved-bandwidth
 /tet:te-bandwidth/tet:technology:
 +---:(example)
 +---ro example
 +---ro bandwidth-1? uint32
augment /nw:networks/nw:network/nw:node/nt:termination-point/tet:te
 /tet:interface-switching-capability/tet:max-lsp-bandwidth
 /tet:te-bandwidth/tet:technology:
 +---:(example)
 +---rw example
 +---rw bandwidth-1? uint32

```

The technology specific TE label for this example topology can be specified using the following augment statements:

```

augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes/tet:underlay/tet:primary-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
 +---:(example)
 +---rw example
 +---rw label-1? uint32
augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes/tet:underlay/tet:backup-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
 +---:(example)
 +---rw example
 +---rw label-1? uint32
augment /nw:networks/tet:te/tet:templates/tet:link-template

```

```

 /tet:te-link-attributes/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/tet:te/tet:templates/tet:link-template
 /tet:te-link-attributes/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:label-restrictions/tet:label-restriction
 /tet:label-start/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:label-restrictions/tet:label-restriction
 /tet:label-end/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:underlay/tet:primary-path/tet:path-element/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:underlay/tet:backup-path/tet:path-element/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32

```

```

augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:path-properties/tet:path-route-objects
 /tet:path-route-object/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:from/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:from/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:to/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:to/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te

```

```

 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:underlay/tet:primary-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:underlay/tet:backup-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:path-properties
 /tet:path-route-objects/tet:path-route-object/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:label-restrictions/tet:label-restriction
 /tet:label-start/tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:label-restrictions/tet:label-restriction
 /tet:label-end/tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:underlay/tet:primary-path/tet:path-element/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:

```

```

 +--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:underlay/tet:backup-path/tet:path-element/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:path-properties/tet:path-route-objects
 /tet:path-route-object/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:from/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:from/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:to/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--ro example

```

```

 +---ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:to/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+---:(example)
 +---ro example
 +---ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:underlay/tet:primary-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+---:(example)
 +---ro example
 +---ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:underlay/tet:backup-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+---:(example)
 +---ro example
 +---ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:information-source-entry/tet:connectivity-matrices
 /tet:connectivity-matrix/tet:path-properties
 /tet:path-route-objects/tet:path-route-object/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(example)
 +---ro example
 +---ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+---:(example)
 +---rw example
 +---rw label-1? uint32

```



```

augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:underlay
 /tet:primary-path/tet:path-element/tet:type/tet:label
 /tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:underlay
 /tet:backup-path/tet:path-element/tet:type/tet:label
 /tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities/tet:path-properties
 /tet:path-route-objects/tet:path-route-object/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32

```

```

augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
 +--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:underlay
 /tet:primary-path/tet:path-element/tet:type/tet:label
 /tet:label-hop/tet:te-label/tet:technology:
 +--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:underlay/tet:backup-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
 +--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nw:node/tet:te
 /tet:tunnel-termination-point
 /tet:local-link-connectivities
 /tet:local-link-connectivity/tet:path-properties
 /tet:path-route-objects/tet:path-route-object/tet:type
 /tet:label/tet:label-hop/tet:te-label/tet:technology:
 +--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
 +--:(example)

```

```

 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:underlay/tet:primary-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:te-link-attributes/tet:underlay/tet:backup-path
 /tet:path-element/tet:type/tet:label/tet:label-hop
 /tet:te-label/tet:technology:
+--:(example)
 +--rw example
 +--rw label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry/tet:label-restrictions
 /tet:label-restriction/tet:label-start/tet:te-label
 /tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32
augment /nw:networks/nw:network/nt:link/tet:te
 /tet:information-source-entry/tet:label-restrictions
 /tet:label-restriction/tet:label-end/tet:te-label
 /tet:technology:
+--:(example)
 +--ro example
 +--ro label-1? uint32

```

The YANG module to implement the above example topology can be seen in Appendix C.

## 7. TE Topology YANG Module

This module references [RFC1195], [RFC3209], [RFC3272], [RFC3471], [RFC3630], [RFC3785], [RFC4201], [RFC4202], [RFC4203], [RFC4206], [RFC4872], [RFC5152], [RFC5212], [RFC5305], [RFC5316], [RFC5329], [RFC5392], [RFC6001], [RFC6241], [RFC6991], [RFC7308], [RFC7471], [RFC7579], [RFC7752], [RFC8345], and [I-D.ietf-teas-yang-te-types].

```
<CODE BEGINS> file "ietf-te-topology@2019-02-07.yang"
module ietf-te-topology {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te-topology";

 prefix "tet";

 import ietf-yang-types {
 prefix "yang";
 reference "RFC 6991: Common YANG Data Types";
 }

 import ietf-inet-types {
 prefix "inet";
 reference "RFC 6991: Common YANG Data Types";
 }

 import ietf-te-types {
 prefix "te-types";
 reference
 "I-D.ietf-teas-yang-te-types: Traffic Engineering Common YANG
 Types";
 }

 import ietf-network {
 prefix "nw";
 reference "RFC 8345: A YANG Data Model for Network Topologies";
 }

 import ietf-network-topology {
 prefix "nt";
 reference "RFC 8345: A YANG Data Model for Network Topologies";
 }
}
```

## organization

"IETF Traffic Engineering Architecture and Signaling (TEAS)  
Working Group";

## contact

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## description

"TE topology model for representing and manipulating technology  
agnostic TE Topologies.

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forth in Section 4.c of the IETF Trust's Legal Provisions  
Relating to IETF Documents  
(<http://trustee.ietf.org/license-info>).

This version of this YANG module is part of RFC XXXX; see the

```
 RFC itself for full legal notices.";

revision "2019-02-07" {
 description "Initial revision";
 reference "RFC XXXX: YANG Data Model for TE Topologies";
 // RFC Ed.: replace XXXX with actual RFC number and remove
 // this note
}

/*
 * Features
 */
feature nsrlg {
 description
 "This feature indicates that the system supports NSRLG
 (Not Sharing Risk Link Group).";
}

feature te-topology-hierarchy {
 description
 "This feature indicates that the system allows underlay
 and/or overlay TE topology hierarchy.";
}

feature template {
 description
 "This feature indicates that the system supports
 template configuration.";
}

/*
 * Typedefs
 */
typedef geographic-coordinate-degree {
 type decimal64 {
 fraction-digits 8;
 }
 description
 "Decimal degree (DD) used to express latitude and longitude
 geographic coordinates.";
} // geographic-coordinate-degree
```

```
typedef te-info-source {
 type enumeration {
 enum "unknown" {
 description "The source is unknown.";
 }
 enum "locally-configured" {
 description "Configured entity.";
 }
 enum "ospfv2" {
 description "OSPFv2.";
 }
 enum "ospfv3" {
 description "OSPFv3.";
 }
 enum "isis" {
 description "ISIS.";
 }
 enum "bgp-ls" {
 description "BGP-LS.";
 reference
 "RFC 7752: North-Bound Distribution of Link-State and
 Traffic Engineering (TE) Information Using BGP";
 }
 enum "system-processed" {
 description "System processed entity.";
 }
 enum "other" {
 description "Other source.";
 }
 }
 description
 "Describing the type of source that has provided the
 related information, and the source credibility.";
} // te-info-source

/*
 * Groupings
 */
grouping connectivity-matrix-entry-path-attributes {
 description
```

```
 "Attributes of connectivity matrix entry.";
 leaf is-allowed {
 type boolean;
 description
 "true - switching is allowed,
 false - switching is disallowed.";
 }
 container underlay {
 if-feature te-topology-hierarchy;
 description "Attributes of the te-link underlay.";
 reference
 "RFC 4206: Label Switched Paths (LSP) Hierarchy with
 Generalized Multi-Protocol Label Switching (GMPLS)
 Traffic Engineering (TE)";

 uses te-link-underlay-attributes;
 } // underlay

 uses te-types:generic-path-constraints;
 uses te-types:generic-path-optimization;
 uses te-types:generic-path-properties;
} // connectivity-matrix-entry-path-attributes

grouping geolocation-container {
 description
 "A container containing a GPS location.";
 container geolocation{
 config false;
 description
 "A container containing a GPS location.";
 leaf altitude {
 type int64;
 units millimeter;
 description
 "Distance above the sea level.";
 }
 leaf latitude {
 type geographic-coordinate-degree {
 range "-90..90";
 }
 description

```



```
 "Relative position north or south on the Earth's surface.";
 }
 leaf longitude {
 type geographic-coordinate-degree {
 range "-180..180";
 }
 description
 "Angular distance east or west on the Earth's surface.";
 }
} // gps-location
} // geolocation-container

grouping information-source-state-attributes {
 description
 "The attributes identifying source that has provided the
 related information, and the source credibility.";
 leaf credibility-preference {
 type uint16;
 description
 "The preference value to calculate the traffic
 engineering database credibility value used for
 tie-break selection between different
 information-source values.
 Higher value is more preferable.";
 }
 leaf logical-network-element {
 type string;
 description
 "When applicable, this is the name of a logical network
 element from which the information is learned.";
 } // logical-network-element
 leaf network-instance {
 type string;
 description
 "When applicable, this is the name of a network-instance
 from which the information is learned.";
 } // network-instance
} // information-source-state-attributes

grouping information-source-per-link-attributes {
 description
```

```
 "Per node container of the attributes identifying source that
 has provided the related information, and the source
 credibility.";
 leaf information-source {
 type te-info-source;
 config false;
 description
 "Indicates the type of the information source.";
 }
 leaf information-source-instance {
 type string;
 config false;
 description
 "The name indicating the instance of the information
 source.";
 }
 container information-source-state {
 config false;
 description
 "The container contains state attributes related to
 the information source.";
 uses information-source-state-attributes;
 container topology {
 description
 "When the information is processed by the system,
 the attributes in this container indicate which topology
 is used to process to generate the result information.";
 uses nt:link-ref;
 } // topology
 } // information-source-state
} // information-source-per-link-attributes

grouping information-source-per-node-attributes {
 description
 "Per node container of the attributes identifying source that
 has provided the related information, and the source
 credibility.";
 leaf information-source {
 type te-info-source;
 config false;
 description
```

```
 "Indicates the type of the information source.";
 }
 leaf information-source-instance {
 type string;
 config false;
 description
 "The name indicating the instance of the information
 source.";
 }
 container information-source-state {
 config false;
 description
 "The container contains state attributes related to
 the information source.";
 uses information-source-state-attributes;
 container topology {
 description
 "When the information is processed by the system,
 the attributes in this container indicate which topology
 is used to process to generate the result information.";
 uses nw:node-ref;
 } // topology
 } // information-source-state
} // information-source-per-node-attributes

grouping interface-switching-capability-list {
 description
 "List of Interface Switching Capabilities Descriptors (ISCD)";
 list interface-switching-capability {
 key "switching-capability encoding";
 description
 "List of Interface Switching Capabilities Descriptors (ISCD)
 for this link.";
 reference
 "RFC 3471: Generalized Multi-Protocol Label Switching (GMPLS)
 Signaling Functional Description.
 RFC 4203: OSPF Extensions in Support of Generalized
 Multi-Protocol Label Switching (GMPLS).";
 }
 leaf switching-capability {
 type identityref {
 base te-types:switching-capabilities;
 }
 }
}
```

```
 }
 description
 "Switching Capability for this interface.";
 }
 leaf encoding {
 type identityref {
 base te-types:lsp-encoding-types;
 }
 description
 "Encoding supported by this interface.";
 }
 uses te-link-iscd-attributes;
} // interface-switching-capability
} // interface-switching-capability-list

grouping statistics-per-link {
 description
 "Statistics attributes per TE link.";
 leaf discontinuity-time {
 type yang:date-and-time;
 description
 "The time on the most recent occasion at which any one or
 more of this interface's counters suffered a
 discontinuity. If no such discontinuities have occurred
 since the last re-initialization of the local management
 subsystem, then this node contains the time the local
 management subsystem re-initialized itself.";
 }
 /* Administrative attributes */
 leaf disables {
 type yang:counter32;
 description
 "Number of times that link was disabled.";
 }
 leaf enables {
 type yang:counter32;
 description
 "Number of times that link was enabled.";
 }
 leaf maintenance-clears {
 type yang:counter32;
```

```
 description
 "Number of times that link was put out of maintenance.";
 }
 leaf maintenance-sets {
 type yang:counter32;
 description
 "Number of times that link was put in maintenance.";
 }
 leaf modifies {
 type yang:counter32;
 description
 "Number of times that link was modified.";
 }
 /* Operational attributes */
 leaf downs {
 type yang:counter32;
 description
 "Number of times that link was set to operational down.";
 }
 leaf ups {
 type yang:counter32;
 description
 "Number of times that link was set to operational up.";
 }
 /* Recovery attributes */
 leaf fault-clears {
 type yang:counter32;
 description
 "Number of times that link experienced fault clear event.";
 }
 leaf fault-detects {
 type yang:counter32;
 description
 "Number of times that link experienced fault detection.";
 }
 leaf protection-switches {
 type yang:counter32;
 description
 "Number of times that link experienced protection
 switchover.";
 }
}
```

```
leaf protection-reverts {
 type yang:counter32;
 description
 "Number of times that link experienced protection
 reversion.";
}
leaf restoration-failures {
 type yang:counter32;
 description
 "Number of times that link experienced restoration
 failure.";
}
leaf restoration-starts {
 type yang:counter32;
 description
 "Number of times that link experienced restoration
 start.";
}
leaf restoration-successes {
 type yang:counter32;
 description
 "Number of times that link experienced restoration
 success.";
}
leaf restoration-reversion-failures {
 type yang:counter32;
 description
 "Number of times that link experienced restoration reversion
 failure.";
}
leaf restoration-reversion-starts {
 type yang:counter32;
 description
 "Number of times that link experienced restoration reversion
 start.";
}
leaf restoration-reversion-successes {
 type yang:counter32;
 description
 "Number of times that link experienced restoration reversion
 success.";
```

```
 }
 } // statistics-per-link

 grouping statistics-per-node {
 description
 "Statistics attributes per TE node.";
 leaf discontinuity-time {
 type yang:date-and-time;
 description
 "The time on the most recent occasion at which any one or
 more of this interface's counters suffered a
 discontinuity. If no such discontinuities have occurred
 since the last re-initialization of the local management
 subsystem, then this node contains the time the local
 management subsystem re-initialized itself.";
 }
 container node {
 description
 "Containing TE node level statistics attributes.";
 leaf disables {
 type yang:counter32;
 description
 "Number of times that node was disabled.";
 }
 leaf enables {
 type yang:counter32;
 description
 "Number of times that node was enabled.";
 }
 leaf maintenance-sets {
 type yang:counter32;
 description
 "Number of times that node was put in maintenance.";
 }
 leaf maintenance-clears {
 type yang:counter32;
 description
 "Number of times that node was put out of maintenance.";
 }
 leaf modifies {
 type yang:counter32;
```

```
 description
 "Number of times that node was modified.";
 }
} // node
container connectivity-matrix-entry {
 description
 "Containing connectivity matrix entry level statistics
 attributes.";
 leaf creates {
 type yang:counter32;
 description
 "Number of times that a connectivity matrix entry was
 created.";
 reference
 "RFC 6241. Section 7.2 for 'create' operation. ";
 }
 leaf deletes {
 type yang:counter32;
 description
 "Number of times that a connectivity matrix entry was
 deleted.";
 reference
 "RFC 6241. Section 7.2 for 'delete' operation. ";
 }
 leaf disables {
 type yang:counter32;
 description
 "Number of times that a connectivity matrix entry was
 disabled.";
 }
 leaf enables {
 type yang:counter32;
 description
 "Number of times that a connectivity matrix entry was
 enabled.";
 }
 leaf modifies {
 type yang:counter32;
 description
 "Number of times that a connectivity matrix entry was
 modified.";
```



```
 }
 } // connectivity-matrix-entry
} // statistics-per-node

grouping statistics-per-ttp {
 description
 "Statistics attributes per TE TTP (Tunnel Termination Point).";
 leaf discontinuity-time {
 type yang:date-and-time;
 description
 "The time on the most recent occasion at which any one or
 more of this interface's counters suffered a
 discontinuity. If no such discontinuities have occurred
 since the last re-initialization of the local management
 subsystem, then this node contains the time the local
 management subsystem re-initialized itself.";
 }
 container tunnel-termination-point {
 description
 "Containing TE TTP (Tunnel Termination Point) level
 statistics attributes.";
 /* Administrative attributes */
 leaf disables {
 type yang:counter32;
 description
 "Number of times that TTP was disabled.";
 }
 leaf enables {
 type yang:counter32;
 description
 "Number of times that TTP was enabled.";
 }
 leaf maintenance-clears {
 type yang:counter32;
 description
 "Number of times that TTP was put out of maintenance.";
 }
 leaf maintenance-sets {
 type yang:counter32;
 description
 "Number of times that TTP was put in maintenance.";
 }
 }
}
```

```
 }
 leaf modifies {
 type yang:counter32;
 description
 "Number of times that TTP was modified.";
 }
 /* Operational attributes */
 leaf downs {
 type yang:counter32;
 description
 "Number of times that TTP was set to operational down.";
 }
 leaf ups {
 type yang:counter32;
 description
 "Number of times that TTP was set to operational up.";
 }
 leaf in-service-clears {
 type yang:counter32;
 description
 "Number of times that TTP was taken out of service
 (TE tunnel was released).";
 }
 leaf in-service-sets {
 type yang:counter32;
 description
 "Number of times that TTP was put in service by a TE
 tunnel (TE tunnel was set up).";
 }
} // tunnel-termination-point

container local-link-connectivity {
 description
 "Containing TE LLCL (Local Link Connectivity List) level
 statistics attributes.";
 leaf creates {
 type yang:counter32;
 description
 "Number of times that an LLCL entry was created.";
 reference
 "RFC 6241. Section 7.2 for 'create' operation.";
 }
}
```

```
 }
 leaf deletes {
 type yang:counter32;
 description
 "Number of times that an LLCL entry was deleted.";
 reference
 "RFC 6241. Section 7.2 for 'delete' operation.";
 }
 leaf disables {
 type yang:counter32;
 description
 "Number of times that an LLCL entry was disabled.";
 }
 leaf enables {
 type yang:counter32;
 description
 "Number of times that an LLCL entry was enabled.";
 }
 leaf modifies {
 type yang:counter32;
 description
 "Number of times that an LLCL entry was modified.";
 }
 } // local-link-connectivity
} // statistics-per-ttp

grouping te-link-augment {
 description
 "Augmentation for TE link.";
 uses te-link-config;
 uses te-link-state-derived;
 container statistics {
 config false;
 description
 "Statistics data.";
 uses statistics-per-link;
 } // statistics
} // te-link-augment

grouping te-link-config {
 description
```

```
"TE link configuration grouping.";
choice bundle-stack-level {
 description
 "The TE link can be partitioned into bundled
 links, or component links.";
 case bundle {
 container bundled-links {
 description
 "A set of bundled links.";
 reference
 "RFC 4201: Link Bundling in MPLS Traffic Engineering
 (TE).";
 list bundled-link {
 key "sequence";
 description
 "Specify a bundled interface that is
 further partitioned.";
 leaf sequence {
 type uint32;
 description
 "Identify the sequence in the bundle.";
 }
 } // list bundled-link
 }
 }
 case component {
 container component-links {
 description
 "A set of component links";
 list component-link {
 key "sequence";
 description
 "Specify a component interface that is
 sufficient to unambiguously identify the
 appropriate resources";

 leaf sequence {
 type uint32;
 description
 "Identify the sequence in the bundle.";
 }
 }
 }
 }
}
```

```
 leaf src-interface-ref {
 type string;
 description
 "Reference to component link interface on the
 source node.";
 }
 leaf des-interface-ref {
 type string;
 description
 "Reference to component link interface on the
 destination node.";
 }
 }
}
} // bundle-stack-level

leaf-list te-link-template {
 if-feature template;
 type leafref {
 path "../.../te/templates/link-template/name";
 }
 description
 "The reference to a TE link template.";
}
uses te-link-config-attributes;
} // te-link-config

grouping te-link-config-attributes {
 description
 "Link configuration attributes in a TE topology.";
 container te-link-attributes {
 description "Link attributes in a TE topology.";
 leaf access-type {
 type te-types:te-link-access-type;
 description
 "Link access type, which can be point-to-point or
 multi-access.";
 }
 container external-domain {
 description

```

```
 "For an inter-domain link, specify the attributes of
 the remote end of link, to facilitate the signalling at
 local end.";
 uses nw:network-ref;
 leaf remote-te-node-id {
 type te-types:te-node-id;
 description
 "Remote TE node identifier, used together with
 remote-te-link-id to identify the remote link
 termination point in a different domain.";
 }
 leaf remote-te-link-tp-id {
 type te-types:te-tp-id;
 description
 "Remote TE link termination point identifier, used
 together with remote-te-node-id to identify the remote
 link termination point in a different domain.";
 }
}
leaf is-abstract {
 type empty;
 description "Present if the link is abstract.";
}
leaf name {
 type string;
 description "Link Name.";
}
container underlay {
 if-feature te-topology-hierarchy;
 description "Attributes of the te-link underlay.";
 reference
 "RFC 4206: Label Switched Paths (LSP) Hierarchy with
 Generalized Multi-Protocol Label Switching (GMPLS)
 Traffic Engineering (TE)";

 uses te-link-underlay-attributes;
} // underlay
leaf admin-status {
 type te-types:te-admin-status;
 description
 "The administrative state of the link.";
```

```
 }

 uses te-link-info-attributes;
 } // te-link-attributes
} // te-link-config-attributes

grouping te-link-info-attributes {
 description
 "Advertised TE information attributes.";
 leaf link-index {
 type uint64;
 description
 "The link identifier. If OSPF is used, this represents an
 ospfLsdbID. If IS-IS is used, this represents an isisLSPID.
 If a locally configured link is used, this object represents
 a unique value, which is locally defined in a router.";
 }
 leaf administrative-group {
 type te-types:admin-groups;
 description
 "Administrative group or color of the link.
 This attribute covers both administrative group (defined in
 RFC 3630, RFC 5305 and RFC 5329), and extended
 administrative group (defined in RFC 7308).";
 }
}

uses interface-switching-capability-list;
uses te-types:label-set-info;

leaf link-protection-type {
 type identityref {
 base te-types:link-protection-type;
 }
 description
 "Link Protection Type desired for this link.";
 reference
 "RFC 4202: Routing Extensions in Support of
 Generalized Multi-Protocol Label Switching (GMPLS).";
}

container max-link-bandwidth {
```

```
 uses te-types:te-bandwidth;
 description
 "Maximum bandwidth that can be seen on this link in this
 direction. Units in bytes per second.";
 reference
 "RFC 3630: Traffic Engineering (TE) Extensions to OSPF
 Version 2.
 RFC 5305: IS-IS Extensions for Traffic Engineering.";
}
container max-resv-link-bandwidth {
 uses te-types:te-bandwidth;
 description
 "Maximum amount of bandwidth that can be reserved in this
 direction in this link. Units in bytes per second.";
 reference
 "RFC 3630: Traffic Engineering (TE) Extensions to OSPF
 Version 2.
 RFC 5305: IS-IS Extensions for Traffic Engineering.";
}
list unreserved-bandwidth {
 key "priority";
 max-elements "8";
 description
 "Unreserved bandwidth for 0-7 priority levels. Units in
 bytes per second.";
 reference
 "RFC 3630: Traffic Engineering (TE) Extensions to OSPF
 Version 2.
 RFC 5305: IS-IS Extensions for Traffic Engineering.";
 leaf priority {
 type uint8 {
 range "0..7";
 }
 description "Priority.";
 }
 uses te-types:te-bandwidth;
}
leaf te-default-metric {
 type uint32;
 description
 "Traffic engineering metric.";
```



```
 reference
 "RFC 3630: Traffic Engineering (TE) Extensions to OSPF
 Version 2.
 RFC 5305: IS-IS Extensions for Traffic Engineering.";
 }
 leaf te-delay-metric {
 type uint32;
 description
 "Traffic engineering delay metric.";
 reference
 "RFC 7471: OSPF Traffic Engineering (TE) Metric Extensions.";
 }
 leaf te-igp-metric {
 type uint32;
 description
 "IGP metric used for traffic engineering.";
 reference
 "RFC 3785: Use of Interior Gateway Protocol (IGP) Metric as a
 Second MPLS Traffic Engineering (TE) Metric.";
 }
 container te-srlgs {
 description
 "Containing a list of SLRGs.";
 leaf-list value {
 type te-types:srlg;
 description "SRLG value.";
 reference
 "RFC 4202: Routing Extensions in Support of
 Generalized Multi-Protocol Label Switching (GMPLS).";
 }
 }
 container te-nsrlgs {
 if-feature nsrlg;
 description
 "Containing a list of NSRLGs (Not Sharing Risk Link
 Groups).
 When an abstract TE link is configured, this list specifies
 the request that underlay TE paths need to be mutually
 disjoint with other TE links in the same groups.";
 leaf-list id {
 type uint32;
```

```
 description
 "NSRLG ID, uniquely configured within a topology.";
 reference
 "RFC 4872: RSVP-TE Extensions in Support of End-to-End
 Generalized Multi-Protocol Label Switching (GMPLS)
 Recovery";
 }
}
} // te-link-info-attributes

grouping te-link-iscd-attributes {
 description
 "TE link ISCD (Interface Switching Capability Descriptor)
 attributes.";
 reference
 "Sec 1.4, RFC 4203: OSPF Extensions in Support of Generalized
 Multi-Protocol Label Switching (GMPLS). Section 1.4.";
 list max-lsp-bandwidth {
 key "priority";
 max-elements "8";
 description
 "Maximum LSP Bandwidth at priorities 0-7.";
 leaf priority {
 type uint8 {
 range "0..7";
 }
 description "Priority.";
 }
 uses te-types:te-bandwidth;
 }
} // te-link-iscd-attributes

grouping te-link-state-derived {
 description
 "Link state attributes in a TE topology.";
 leaf oper-status {
 type te-types:te-oper-status;
 config false;
 description
 "The current operational state of the link.";
 }
}
```

```
leaf is-transitional {
 type empty;
 config false;
 description
 "Present if the link is transitional, used as an
 alternative approach in lieu of inter-layer-lock-id
 for path computation in a TE topology covering multiple
 layers or multiple regions.";
 reference
 "RFC 5212: Requirements for GMPLS-Based Multi-Region and
 Multi-Layer Networks (MRN/MLN).
 RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
 for Multi-Layer and Multi-Region Networks (MLN/MRN).";
}
uses information-source-per-link-attributes;
list information-source-entry {
 key "information-source information-source-instance";
 config false;
 description
 "A list of information sources learned, including the one
 used.";
 uses information-source-per-link-attributes;
 uses te-link-info-attributes;
}
container recovery {
 config false;
 description
 "Status of the recovery process.";
 leaf restoration-status {
 type te-types:te-recovery-status;
 description
 "Restoration status.";
 }
 leaf protection-status {
 type te-types:te-recovery-status;
 description
 "Protection status.";
 }
}
container underlay {
 if-feature te-topology-hierarchy;
```

```
 config false;
 description "State attributes for te-link underlay.";
 leaf dynamic {
 type boolean;
 description
 "true if the underlay is dynamically created.";
 }
 leaf committed {
 type boolean;
 description
 "true if the underlay is committed.";
 }
}
} // te-link-state-derived

grouping te-link-underlay-attributes {
 description "Attributes for te-link underlay.";
 reference
 "RFC 4206: Label Switched Paths (LSP) Hierarchy with
 Generalized Multi-Protocol Label Switching (GMPLS)
 Traffic Engineering (TE)";
 leaf enabled {
 type boolean;
 description
 "'true' if the underlay is enabled.
 'false' if the underlay is disabled.";
 }
}
container primary-path {
 description
 "The service path on the underlay topology that
 supports this link.";
 uses nw:network-ref;
 list path-element {
 key "path-element-id";
 description
 "A list of path elements describing the service path.";
 leaf path-element-id {
 type uint32;
 description "To identify the element in a path.";
 }
 }
 uses te-path-element;
```

```
 }
 } // primary-path
 list backup-path {
 key "index";
 description
 "A list of backup service paths on the underlay topology that
 protect the underlay primary path. If the primary path is
 not protected, the list contains zero elements. If the
 primary path is protected, the list contains one or more
 elements.";
 leaf index {
 type uint32;
 description
 "A sequence number to identify a backup path.";
 }
 uses nw:network-ref;
 list path-element {
 key "path-element-id";
 description
 "A list of path elements describing the backup service
 path";
 leaf path-element-id {
 type uint32;
 description "To identify the element in a path.";
 }
 uses te-path-element;
 }
 } // underlay-backup-path
 leaf protection-type {
 type identityref {
 base te-types:lsp-protection-type;
 }
 description
 "Underlay protection type desired for this link.";
 }
 container tunnel-termination-points {
 description
 "Underlay TTP (Tunnel Termination Points) desired for this
 link.";
 leaf source {
 type binary;
 }
 }
}
```

```
 description
 "Source tunnel termination point identifier.";
 }
 leaf destination {
 type binary;
 description
 "Destination tunnel termination point identifier.";
 }
}
container tunnels {
 description
 "Underlay TE tunnels supporting this TE link.";
 leaf sharing {
 type boolean;
 default true;
 description
 "'true' if the underlay tunnel can be shared with other
 TE links;
 'false' if the underlay tunnel is dedicated to this
 TE link.
 This leaf is the default option for all TE tunnels,
 and may be overridden by the per TE tunnel value.";
 }
 list tunnel {
 key "tunnel-name";
 description
 "Zero, one or more underlay TE tunnels that support this TE
 link.";
 leaf tunnel-name {
 type string;
 description
 "A tunnel name uniquely identifies an underlay TE tunnel,
 used together with the source-node of this link.
 The detailed information of this tunnel can be retrieved
 from the ietf-te model.";
 reference "RFC 3209";
 }
 }
 leaf sharing {
 type boolean;
 description
 "'true' if the underlay tunnel can be shared with other
```

```
 TE links;
 'false' if the underlay tunnel is dedicated to this
 TE link.";
 }
} // tunnel
} // tunnels
} // te-link-underlay-attributes

grouping te-node-augment {
 description
 "Augmentation for TE node.";
 uses te-node-config;
 uses te-node-state-derived;
 container statistics {
 config false;
 description
 "Statistics data.";
 uses statistics-per-node;
 } // statistics

 list tunnel-termination-point {
 key "tunnel-tp-id";
 description
 "A termination point can terminate a tunnel.";
 leaf tunnel-tp-id {
 type binary;
 description
 "Tunnel termination point identifier.";
 }

 uses te-node-tunnel-termination-point-config;
 leaf oper-status {
 type te-types:te-oper-status;
 config false;
 description
 "The current operational state of the tunnel
 termination point.";
 }
 uses geolocation-container;
 container statistics {
 config false;
```

```
 description
 "Statistics data.";
 uses statistics-per-ttp;
 } // statistics

 // Relations to other tunnel termination points
 list supporting-tunnel-termination-point {
 key "node-ref tunnel-tp-ref";
 description
 "Identifies the tunnel termination points, that this
 tunnel termination point is depending on.";
 leaf node-ref {
 type inet:uri;
 description
 "This leaf identifies the node in which the supporting
 tunnel termination point is present.
 This node is either the supporting node or a node in an
 underlay topology.";
 }
 leaf tunnel-tp-ref {
 type binary;
 description
 "Reference to a tunnel termination point, which is
 either in the supporting node or a node in an
 underlay topology.";
 }
 } // supporting-tunnel-termination-point
} // tunnel-termination-point
} // te-node-augment

grouping te-node-config {
 description "TE node configuration grouping.";
 leaf-list te-node-template {
 if-feature template;
 type leafref {
 path "../.../.../te/templates/node-template/name";
 }
 description
 "The reference to a TE node template.";
 }
 uses te-node-config-attributes;
```



```
 } // te-node-config

 grouping te-node-config-attributes {
 description "Configuration node attributes in a TE topology.";
 container te-node-attributes {
 description "Containing node attributes in a TE topology.";
 leaf admin-status {
 type te-types:te-admin-status;
 description
 "The administrative state of the link.";
 }
 uses te-node-connectivity-matrices;
 uses te-node-info-attributes;
 } // te-node-attributes
 } // te-node-config-attributes

 grouping te-node-config-attributes-template {
 description
 "Configuration node attributes for template in a TE topology.";
 container te-node-attributes {
 description "Containing node attributes in a TE topology.";
 leaf admin-status {
 type te-types:te-admin-status;
 description
 "The administrative state of the link.";
 }
 uses te-node-info-attributes;
 } // te-node-attributes
 } // te-node-config-attributes-template

 grouping te-node-connectivity-matrices {
 description "Connectivity matrix on a TE node.";
 container connectivity-matrices {
 description
 "Containing connectivity matrix on a TE node.";
 leaf number-of-entries {
 type uint16;
 description
 "The number of connectivity matrix entries.
 If this number is specified in the configuration request,
 the number is requested number of entries, which may not
```

```
 all be listed in the list;
 if this number is reported in the state data,
 the number is the current number of operational entries.";
 }
 uses te-types:label-set-info;
 uses connectivity-matrix-entry-path-attributes;
 list connectivity-matrix {
 key "id";
 description
 "Represents node's switching limitations, i.e. limitations
 in interconnecting network TE links across the node.";
 reference
 "RFC 7579: General Network Element Constraint Encoding
 for GMPLS-Controlled Networks.";
 leaf id {
 type uint32;
 description "Identifies the connectivity-matrix entry.";
 }
 } // connectivity-matrix
} // connectivity-matrices
} // te-node-connectivity-matrices

grouping te-node-connectivity-matrix-attributes {
 description
 "Termination point references of a connectivity matrix entry.";
 container from {
 description
 "Reference to source link termination point.";
 leaf tp-ref {
 type leafref {
 path "../..//../..//../nt:termination-point/nt:tp-id";
 }
 description
 "Relative reference to a termination point.";
 }
 uses te-types:label-set-info;
 }
 container to {
 description
 "Reference to destination link termination point.";
 leaf tp-ref {
```

```
 type leafref {
 path "../.../.../.../nt:termination-point/nt:tp-id";
 }
 description
 "Relative reference to a termination point.";
 }
 uses te-types:label-set-info;
}
uses connectivity-matrix-entry-path-attributes;
} // te-node-connectivity-matrix-attributes

grouping te-node-info-attributes {
 description
 "Advertised TE information attributes.";
 leaf domain-id {
 type uint32;
 description
 "Identifies the domain that this node belongs.
 This attribute is used to support inter-domain links.";
 reference
 "RFC 5152: A Per-Domain Path Computation Method for
 Establishing Inter-Domain Traffic Engineering (TE)
 Label Switched Paths (LSPs).
 RFC 5392: OSPF Extensions in Support of Inter-Autonomous
 System (AS) MPLS and GMPLS Traffic Engineering.
 RFC 5316: ISIS Extensions in Support of Inter-Autonomous
 System (AS) MPLS and GMPLS Traffic Engineering.";
 }
 leaf is-abstract {
 type empty;
 description
 "Present if the node is abstract, not present if the node
 is actual.";
 }
 leaf name {
 type string;
 description "Node name.";
 }
 leaf-list signaling-address {
 type inet:ip-address;
 description "Node signaling address.";
```

```
 }
 container underlay-topology {
 if-feature te-topology-hierarchy;
 description
 "When an abstract node encapsulates a topology,
 the attributes in this container point to said topology.";
 uses nw:network-ref;
 }
 } // te-node-info-attributes

grouping te-node-state-derived {
 description "Node state attributes in a TE topology.";
 leaf oper-status {
 type te-types:te-oper-status;
 config false;
 description
 "The current operational state of the node.";
 }
 uses geolocation-container;
 leaf is-multi-access-dr {
 type empty;
 config false;
 description
 "The presence of this attribute indicates that this TE node
 is a pseudonode elected as a designated router.";
 reference
 "RFC 3630: Traffic Engineering (TE) Extensions to OSPF
 Version 2.
 RFC 1195: Use of OSI IS-IS for Routing in TCP/IP and Dual
 Environments.";
 }
 uses information-source-per-node-attributes;
 list information-source-entry {
 key "information-source information-source-instance";
 config false;
 description
 "A list of information sources learned, including the one
 used.";
 uses information-source-per-node-attributes;
 uses te-node-connectivity-matrices;
 uses te-node-info-attributes;
 }
}
```

```
 }
 } // te-node-state-derived

 grouping te-node-tunnel-termination-point-config {
 description
 "Termination capability of a tunnel termination point on a
 TE node.";
 uses te-node-tunnel-termination-point-config-attributes;
 container local-link-connectivities {
 description
 "Containing local link connectivity list for
 a tunnel termination point on a TE node.";
 leaf number-of-entries {
 type uint16;
 description
 "The number of local link connectivity list entries.
 If this number is specified in the configuration request,
 the number is requested number of entries, which may not
 all be listed in the list;
 if this number is reported in the state data,
 the number is the current number of operational entries.";
 }
 uses te-types:label-set-info;
 uses connectivity-matrix-entry-path-attributes;
 } // local-link-connectivities
 } // te-node-tunnel-termination-point-config

 grouping te-node-tunnel-termination-point-config-attributes {
 description
 "Configuration attributes of a tunnel termination point on a
 TE node.";
 leaf admin-status {
 type te-types:te-admin-status;
 description
 "The administrative state of the tunnel termination point.";
 }
 leaf name {
 type string;
 description
 "A descriptive name for the tunnel termination point.";
 }
 }
```

```
leaf switching-capability {
 type identityref {
 base te-types:switching-capabilities;
 }
 description
 "Switching Capability for this interface.";
}
leaf encoding {
 type identityref {
 base te-types:lsp-encoding-types;
 }
 description
 "Encoding supported by this interface.";
}
leaf-list inter-layer-lock-id {
 type uint32;
 description
 "Inter layer lock ID, used for path computation in a TE
 topology covering multiple layers or multiple regions.";
 reference
 "RFC 5212: Requirements for GMPLS-Based Multi-Region and
 Multi-Layer Networks (MRN/MLN).
 RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
 for Multi-Layer and Multi-Region Networks (MLN/MRN).";
}
leaf protection-type {
 type identityref {
 base te-types:lsp-protection-type;
 }
 description
 "The protection type that this tunnel termination point
 is capable of.";
}

container client-layer-adaptation {
 description
 "Containing capability information to support a client layer
 adaption in multi-layer topology.";
 list switching-capability {
 key "switching-capability encoding";
 description
```

```
 "List of supported switching capabilities";
 reference
 "RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
 for Multi-Layer and Multi-Region Networks (MLN/MRN).
 RFC 4202: Routing Extensions in Support of
 Generalized Multi-Protocol Label Switching (GMPLS).";
 leaf switching-capability {
 type identityref {
 base te-types:switching-capabilities;
 }
 description
 "Switching Capability for the client layer adaption.";
 }
 leaf encoding {
 type identityref {
 base te-types:lsp-encoding-types;
 }
 description
 "Encoding supported by the client layer adaption.";
 }
 uses te-types:te-bandwidth;
}
}
} // te-node-tunnel-termination-point-config-attributes

grouping te-node-tunnel-termination-point-llc-list {
 description
 "Local link connectivity list of a tunnel termination
 point on a TE node.";
 list local-link-connectivity {
 key "link-tp-ref";
 description
 "The termination capabilities between
 tunnel-termination-point and link termination-point.
 The capability information can be used to compute
 the tunnel path.
 The Interface Adjustment Capability Descriptors (IACD)
 (defined in RFC 6001) on each link-tp can be derived from
 this local-link-connectivity list.";
 reference
 "RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
```

```
 for Multi-Layer and Multi-Region Networks (MLN/MRN).";

 leaf link-tp-ref {
 type leafref {
 path "../..../nt:termination-point/nt:tp-id";
 }
 description
 "Link termination point.";
 }
 uses te-types:label-set-info;
 uses connectivity-matrix-entry-path-attributes;
} // local-link-connectivity
} // te-node-tunnel-termination-point-config

grouping te-path-element {
 description
 "A group of attributes defining an element in a TE path
 such as TE node, TE link, TE atomic resource or label.";
 uses te-types:explicit-route-hop;
} // te-path-element

grouping te-termination-point-augment {
 description
 "Augmentation for TE termination point.";
 leaf te-tp-id {
 type te-types:te-tp-id;
 description
 "An identifier to uniquely identify a TE termination
 point.";
 }
 container te {
 must "../te-tp-id";
 presence "TE support.";
 description
 "Indicates TE support.";

 uses te-termination-point-config;
 leaf oper-status {
 type te-types:te-oper-status;
 config false;
 description
```



```
 "The current operational state of the link termination
 point.";
 }
 uses geolocation-container;
} // te
} // te-termination-point-augment

grouping te-termination-point-config {
 description
 "TE termination point configuration grouping.";
 leaf admin-status {
 type te-types:te-admin-status;
 description
 "The administrative state of the link termination point.";
 }
 leaf name {
 type string;
 description
 "A descriptive name for the link termination point.";
 }
 uses interface-switching-capability-list;
 leaf inter-domain-plug-id {
 type binary;
 description
 "A topology-wide unique number that identifies on the
 network a connectivity supporting a given inter-domain
 TE link. This is more flexible alternative to specifying
 remote-te-node-id and remote-te-link-tp-id on a TE link,
 when the provider does not know remote-te-node-id and
 remote-te-link-tp-id or need to give client the
 flexibility to mix-n-match multiple topologies.";
 }
 leaf-list inter-layer-lock-id {
 type uint32;
 description
 "Inter layer lock ID, used for path computation in a TE
 topology covering multiple layers or multiple regions.";
 reference
 "RFC 5212: Requirements for GMPLS-Based Multi-Region and
 Multi-Layer Networks (MRN/MLN).
 RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
```

```
 for Multi-Layer and Multi-Region Networks (MLN/MRN).";
 }
} // te-termination-point-config

grouping te-topologies-augment {
 description
 "Augmentation for TE topologies.";
 container te {
 presence "TE support.";
 description
 "Indicates TE support.";

 container templates {
 description
 "Configuration parameters for templates used for TE
 topology.";

 list node-template {
 if-feature template;
 key "name";
 leaf name {
 type te-types:te-template-name;
 description
 "The name to identify a TE node template.";
 }
 description
 "The list of TE node templates used to define sharable
 and reusable TE node attributes.";
 uses template-attributes;
 uses te-node-config-attributes-template;
 } // node-template

 list link-template {
 if-feature template;
 key "name";
 leaf name {
 type te-types:te-template-name;
 description
 "The name to identify a TE link template.";
 }
 description

```

```
 "The list of TE link templates used to define sharable
 and reusable TE link attributes.";
 uses template-attributes;
 uses te-link-config-attributes;
 } // link-template
} // templates
} // te
} // te-topologies-augment

grouping te-topology-augment {
 description
 "Augmentation for TE topology.";
 uses te-types:te-topology-identifier;

 container te {
 must "../te-topology-identifier/provider-id"
 + " and ../te-topology-identifier/client-id"
 + " and ../te-topology-identifier/topology-id";
 presence "TE support.";
 description
 "Indicates TE support.";

 uses te-topology-config;
 uses geolocation-container;
 } // te
} // te-topology-augment

grouping te-topology-config {
 description
 "TE topology configuration grouping.";
 leaf name {
 type string;
 description
 "Name of the TE topology. This attribute is optional and can
 be specified by the operator to describe the TE topology,
 which can be useful when network-id is not descriptive
 and not modifiable because of being generated by the
 system.";
 }
 leaf preference {
 type uint8 {
```

```
 range "1..255";
 }
 description
 "Specifies a preference for this topology. A lower number
 indicates a higher preference.";
}
leaf optimization-criterion {
 type identityref {
 base te-types:objective-function-type;
 }
 description
 "Optimization criterion applied to this topology.";
 reference
 "RFC 3272: Overview and Principles of Internet Traffic
 Engineering.";
}
list nsrlg {
 if-feature nsrlg;
 key "id";
 description
 "List of NSRLGs (Not Sharing Risk Link Groups).";
 reference
 "RFC 4872: RSVP-TE Extensions in Support of End-to-End
 Generalized Multi-Protocol Label Switching (GMPLS)
 Recovery";
 leaf id {
 type uint32;
 description
 "Identify the NSRLG entry.";
 }
 leaf disjointness {
 type te-types:te-path-disjointness;
 description
 "The type of resource disjointness.";
 }
} // nsrlg
} // te-topology-config

grouping template-attributes {
 description
 "Common attributes for all templates.";
```

```
leaf priority {
 type uint16;
 description
 "The preference value to resolve conflicts between different
 templates. When two or more templates specify values for
 one configuration attribute, the value from the template
 with the highest priority is used.
 A lower number indicates a higher priority. The highest
 priority is 0.";
}
leaf reference-change-policy {
 type enumeration {
 enum no-action {
 description
 "When an attribute changes in this template, the
 configuration node referring to this template does
 not take any action.";
 }
 enum not-allowed {
 description
 "When any configuration object has a reference to this
 template, changing this template is not allowed.";
 }
 enum cascade {
 description
 "When an attribute changes in this template, the
 configuration object referring to this template applies
 the new attribute value to the corresponding
 configuration.";
 }
 }
 description
 "This attribute specifies the action taken to a configuration
 node that has a reference to this template.";
}
} // template-attributes

/*
 * Data nodes
 */
augment "/nw:networks/nw:network/nw:network-types" {
```

```
 description
 "Introduce new network type for TE topology.";
 container te-topology {
 presence "Indicates TE topology.";
 description
 "Its presence identifies the TE topology type.";
 }
 }

 augment "/nw:networks" {
 description
 "Augmentation parameters for TE topologies.";
 uses te-topologies-augment;
 }

 augment "/nw:networks/nw:network" {
 when "nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE topology.";
 uses te-topology-augment;
 }

 augment "/nw:networks/nw:network/nw:node" {
 when "../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE at node level.";
 leaf te-node-id {
 type te-types:te-node-id;
 description
 "The identifier of a node in the TE topology.
 A node is specific to a topology to which it belongs.";
 }
 }
 container te {
```

```
 must "../te-node-id" {
 description
 "te-node-id is mandatory.";
 }
 must "count(..../nw:supporting-node)<=1" {
 description
 "For a node in a TE topology, there cannot be more
 than 1 supporting node. If multiple nodes are abstracted,
 the underlay-topology is used.";
 }
 presence "TE support.";
 description
 "Indicates TE support.";
 uses te-node-augment;
 } // te
}

augment "/nw:networks/nw:network/nt:link" {
 when "../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE at link level.";
 container te {
 must "count(..../nt:supporting-link)<=1" {
 description
 "For a link in a TE topology, there cannot be more
 than 1 supporting link. If one or more link paths are
 abstracted, the underlay is used.";
 }
 presence "TE support.";
 description
 "Indicates TE support.";
 uses te-link-augment;
 } // te
}

augment "/nw:networks/nw:network/nw:node/"
 + "nt:termination-point" {
```

```
when "../../../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
}
description
 "Configuration parameters for TE at termination point level.";
uses te-termination-point-augment;
}

augment
 "/nw:networks/nw:network/nt:link/te/bundle-stack-level/"
+ "bundle/bundled-links/bundled-link" {
 when "../../../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE link bundled link.";
 leaf src-tp-ref {
 type leafref {
 path "../../../nw:node[nw:node-id = "
 + "current()/../../../../nt:source/"
 + "nt:source-node]/"
 + "nt:termination-point/nt:tp-id";
 require-instance true;
 }
 description
 "Reference to another TE termination point on the
 same source node.";
 }
 leaf des-tp-ref {
 type leafref {
 path "../../../nw:node[nw:node-id = "
 + "current()/../../../../nt:destination/"
 + "nt:dest-node]/"
 + "nt:termination-point/nt:tp-id";
 require-instance true;
 }
 description

```



```
 "Reference to another TE termination point on the
 same destination node.";
 }
}

augment
 "/nw:networks/nw:network/nw:node/te/"
+ "information-source-entry/connectivity-matrices/"
+ "connectivity-matrix" {
 when "../..../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE node connectivity-matrix.";
 uses te-node-connectivity-matrix-attributes;
}

augment
 "/nw:networks/nw:network/nw:node/te/te-node-attributes/"
+ "connectivity-matrices/connectivity-matrix" {
 when "../..../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE node connectivity-matrix.";
 uses te-node-connectivity-matrix-attributes;
}

augment
 "/nw:networks/nw:network/nw:node/te/"
+ "tunnel-termination-point/local-link-connectivities" {
 when "../..../nw:network-types/tet:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
```

```
 "Augment TE node tunnel termination point LLCs
 (Local Link Connectivities).";
 uses te-node-tunnel-termination-point-llc-list;
 }
}
<CODE ENDS>
```

## 8. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

- o /nw:networks/nw:network/nw:network-types/tet:te-topology  
This subtree specifies the TE topology type. Modifying the configurations can make TE topology type invalid. By such modifications, a malicious attacker may disable the TE capabilities on the related networks and cause traffic disrupted or misrouted.
- o /nw:networks/tet:te  
This subtree specifies the TE node templates and TE link templates. Modifying the configurations in this subtree will change the related future TE configurations. By such modifications, a malicious attacker may change the TE capabilities scheduled at a future time, to cause traffic disrupted or misrouted.

- o `/nw:networks/nw:network`  
This subtree specifies the topology-wide configurations, including the TE topology ID and topology-wide policies. Modifying the configurations in this subtree can add, remove, or modify TE topologies. By adding a TE topology, a malicious attacker may create an unauthorized traffic network. By removing or modifying a TE topology, a malicious attacker may cause traffic disabled or misrouted in the specified TE topology. Such traffic changes may also affect the traffic in the connected TE topologies.
- o `/nw:networks/nw:network/nw:node`  
This subtree specifies the configurations for TE nodes. Modifying the configurations in this subtree can add, remove, or modify TE nodes. By adding a TE node, a malicious attacker may create an unauthorized traffic path. By removing or modifying a TE node, a malicious attacker may cause traffic disabled or misrouted in the specified TE node. Such traffic changes may also affect the traffic on the surrounding TE nodes and TE links in this TE topology and the connected TE topologies.
- o `/nw:networks/nw:network/nt:link/tet:te`  
This subtree specifies the configurations for TE links. Modifying the configurations in this subtree can add, remove, or modify TE links. By adding a TE link, a malicious attacker may create an unauthorized traffic path. By removing or modifying a TE link, a malicious attacker may cause traffic disabled or misrouted on the specified TE link. Such traffic changes may also affect the traffic on the surrounding TE nodes and TE links in this TE topology and the connected TE topologies.
- o `/nw:networks/nw:network/nw:node/nt:termination-point`  
This subtree specifies the configurations of TE link termination points. Modifying the configurations in this subtree can add, remove, or modify TE link termination points. By adding a TE link termination point, a malicious attacker may create an unauthorized traffic path. By removing or modifying a TE link termination point, a malicious attacker may cause traffic disabled or misrouted on the specified TE link termination point. Such traffic changes may also affect the traffic on the surrounding TE nodes and TE links in this TE topology and the connected TE topologies.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via `get`, `get-config`, or `notification`) to these data nodes. These are the subtrees and data nodes and their sensitivity/vulnerability:

- o /nw:networks/nw:network/nw:network-types/tet:te-topology  
Unauthorized access to this subtree can disclose the TE topology type.
- o /nw:networks/tet:te  
Unauthorized access to this subtree can disclose the TE node templates and TE link templates.
- o /nw:networks/nw:network  
Unauthorized access to this subtree can disclose the topology-wide configurations, including the TE topology ID, the topology-wide policies, and the topology geolocation.
- o /nw:networks/nw:network/nw:node  
Unauthorized access to this subtree can disclose the operational state information of TE nodes.
- o /nw:networks/nw:network/nt:link/tet:te  
Unauthorized access to this subtree can disclose the operational state information of TE links.
- o /nw:networks/nw:network/nw:node/nt:termination-point  
Unauthorized access to this subtree can disclose the operational state information of TE link termination points.

## 9. IANA Considerations

This document registers the following URIs in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made.

URI: urn:ietf:params:xml:ns:yang:ietf-te-topology  
Registrant Contact: The IESG.  
XML: N/A, the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-te-topology-state  
Registrant Contact: The IESG.  
XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC7950].

name: ietf-te-topology  
namespace: urn:ietf:params:xml:ns:yang:ietf-te-topology  
prefix: tet  
reference: RFC XXXX

name: ietf-te-topology-state  
namespace: urn:ietf:params:xml:ns:yang:ietf-te-topology-state  
prefix: tet-s  
reference: RFC XXXX

## 10. References

### 10.1. Normative References

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## Appendix A. Complete Model Tree Structure

```

module: ietf-te-topology
 augment /nw:networks/nw:network/nw:network-types:
 +--rw te-topology!
 augment /nw:networks:
 +--rw te!
 +--rw templates
 +--rw node-template* [name] {template}?
 +--rw name
 | te-types:te-template-name
 +--rw priority? uint16
 +--rw reference-change-policy? enumeration
 +--rw te-node-attributes
 +--rw admin-status? te-types:te-admin-status
 +--rw domain-id? uint32
 +--rw is-abstract? empty
 +--rw name? string
 +--rw signaling-address* inet:ip-address
 +--rw underlay-topology {te-topology-hierarchy}?
 +--rw network-ref?
 -> /nw:networks/network/network-id
 +--rw link-template* [name] {template}?
 +--rw name
 | te-types:te-template-name
 +--rw priority? uint16
 +--rw reference-change-policy? enumeration
 +--rw te-link-attributes
 +--rw access-type?
 | te-types:te-link-access-type
 +--rw external-domain
 +--rw network-ref?
 | -> /nw:networks/network/network-id
 +--rw remote-te-node-id? te-types:te-node-id
 +--rw remote-te-link-tp-id? te-types:te-tp-id
 +--rw is-abstract? empty
 +--rw name? string
 +--rw underlay {te-topology-hierarchy}?
 +--rw enabled? boolean
 +--rw primary-path
 | +--rw network-ref?

```

```

| -> /nw:networks/network/network-id
+--rw path-element* [path-element-id]
| +--rw path-element-id uint32
| +--rw (type)?
| +--:(numbered-node-hop)
| +--rw numbered-node-hop
| +--rw node-id te-node-id
| +--rw hop-type? te-hop-type
| +--:(numbered-link-hop)
| +--rw numbered-link-hop
| +--rw link-tp-id te-tp-id
| +--rw hop-type? te-hop-type
| +--rw direction?
| te-link-direction
| +--:(unnumbered-link-hop)
| +--rw unnumbered-link-hop
| +--rw link-tp-id te-tp-id
| +--rw node-id te-node-id
| +--rw hop-type? te-hop-type
| +--rw direction?
| te-link-direction
| +--:(as-number)
| +--rw as-number-hop
| +--rw as-number inet:as-number
| +--rw hop-type? te-hop-type
| +--:(label)
| +--rw label-hop
| +--rw te-label
| +--rw (technology)?
| +--:(generic)
| +--rw generic?
| rt-
types:generalized-label
| +--rw direction?
| te-label-direction
+--rw backup-path* [index]
| +--rw index uint32
| +--rw network-ref?
| -> /nw:networks/network/network-id
+--rw path-element* [path-element-id]
| +--rw path-element-id uint32

```

```

+--rw (type)?
+--:(numbered-node-hop)
| +--rw numbered-node-hop
| +--rw node-id te-node-id
| +--rw hop-type? te-hop-type
+--:(numbered-link-hop)
| +--rw numbered-link-hop
| +--rw link-tp-id te-tp-id
| +--rw hop-type? te-hop-type
| +--rw direction?
| te-link-direction
+--:(unnumbered-link-hop)
| +--rw unnumbered-link-hop
| +--rw link-tp-id te-tp-id
| +--rw node-id te-node-id
| +--rw hop-type? te-hop-type
| +--rw direction?
| te-link-direction
+--:(as-number)
| +--rw as-number-hop
| +--rw as-number inet:as-number
| +--rw hop-type? te-hop-type
+--:(label)
| +--rw label-hop
| +--rw te-label
| +--rw (technology)?
| +--:(generic)
| +--rw generic?
| rt-
types:generalized-label
| +--rw direction?
| te-label-direction
+--rw protection-type? identityref
+--rw tunnel-termination-points
| +--rw source? binary
| +--rw destination? binary
+--rw tunnels
| +--rw sharing? boolean
| +--rw tunnel* [tunnel-name]
| +--rw tunnel-name string
| +--rw sharing? boolean

```

```

+--rw admin-status?
| te-types:te-admin-status
+--rw link-index? uint64
+--rw administrative-group?
| te-types:admin-groups
+--rw interface-switching-capability*
| [switching-capability encoding]
| +--rw switching-capability identityref
| +--rw encoding identityref
| +--rw max-lsp-bandwidth* [priority]
| +--rw priority uint8
| +--rw te-bandwidth
| +--rw (technology)?
| +--:(generic)
| +--rw generic? te-bandwidth
+--rw label-restrictions
| +--rw label-restriction* [index]
| +--rw restriction? enumeration
| +--rw index uint32
| +--rw label-start
| +--rw te-label
| +--rw (technology)?
| +--:(generic)
| +--rw generic?
| rt-types:generalized-label
| +--rw direction? te-label-direction
+--rw label-end
| +--rw te-label
| +--rw (technology)?
| +--:(generic)
| +--rw generic?
| rt-types:generalized-label
| +--rw direction? te-label-direction
+--rw label-step
| +--rw (technology)?
| +--:(generic)
| +--rw generic? int32
| +--rw range-bitmap? yang:hex-string
+--rw link-protection-type? identityref
+--rw max-link-bandwidth
| +--rw te-bandwidth

```

```

 | +---rw (technology)?
 | | +---:(generic)
 | | +---rw generic? te-bandwidth
+---rw max-resv-link-bandwidth
 | +---rw te-bandwidth
 | | +---rw (technology)?
 | | +---:(generic)
 | | +---rw generic? te-bandwidth
+---rw unreserved-bandwidth* [priority]
 | +---rw priority uint8
 | +---rw te-bandwidth
 | | +---rw (technology)?
 | | +---:(generic)
 | | +---rw generic? te-bandwidth
+---rw te-default-metric? uint32
+---rw te-delay-metric? uint32
+---rw te-igp-metric? uint32
+---rw te-srlgs
 | +---rw value* te-types:srlg
+---rw te-nsrlgs {nsrlg}?
 | +---rw id* uint32
augment /nw:networks/nw:network:
+---rw te-topology-identifier
 | +---rw provider-id? te-global-id
 | +---rw client-id? te-global-id
 | +---rw topology-id? te-topology-id
+---rw te!
 | +---rw name? string
 | +---rw preference? uint8
 | +---rw optimization-criterion? identityref
 | +---rw nsrlg* [id] {nsrlg}?
 | | +---rw id uint32
 | | +---rw disjointness? te-types:te-path-disjointness
+---ro geolocation
 | +---ro altitude? int64
 | +---ro latitude? geographic-coordinate-degree
 | +---ro longitude? geographic-coordinate-degree
augment /nw:networks/nw:network/nw:node:
+---rw te-node-id? te-types:te-node-id
+---rw te!
 | +---rw te-node-template*

```

```

| -> ../../../../te/templates/node-template/name
| {template}?
+--rw te-node-attributes
| +--rw admin-status? te-types:te-admin-status
| +--rw connectivity-matrices
| | +--rw number-of-entries? uint16
| | +--rw label-restrictions
| | | +--rw label-restriction* [index]
| | | | +--rw restriction? enumeration
| | | | +--rw index uint32
| | | | +--rw label-start
| | | | | +--rw te-label
| | | | | | +--rw (technology)?
| | | | | | | +--:(generic)
| | | | | | | | +--rw generic?
| | | | | | | | | rt-types:generalized-label
| | | | | | | | | +--rw direction? te-label-direction
| | | | +--rw label-end
| | | | | +--rw te-label
| | | | | | +--rw (technology)?
| | | | | | | +--:(generic)
| | | | | | | | +--rw generic?
| | | | | | | | | rt-types:generalized-label
| | | | | | | | | +--rw direction? te-label-direction
| | | | +--rw label-step
| | | | | +--rw (technology)?
| | | | | | +--:(generic)
| | | | | | | +--rw generic? int32
| | | | +--rw range-bitmap? yang:hex-string
| | +--rw is-allowed? boolean
| +--rw underlay {te-topology-hierarchy}?
| | +--rw enabled? boolean
| | +--rw primary-path
| | | +--rw network-ref?
| | | | -> /nw:networks/network/network-id
| | | +--rw path-element* [path-element-id]
| | | | +--rw path-element-id uint32
| | | | +--rw (type)?
| | | | | +--:(numbered-node-hop)
| | | | | | +--rw numbered-node-hop
| | | | | | | +--rw node-id te-node-id

```







```

| +---rw metric-type identityref
| +---rw upper-bound? uint64
+---rw path-affinities-values
| +---rw path-affinities-value* [usage]
| +---rw usage identityref
| +---rw value? admin-groups
+---rw path-affinity-names
| +---rw path-affinity-name* [usage]
| +---rw usage identityref
| +---rw affinity-name* [name]
| +---rw name string
+---rw path-srlgs-lists
| +---rw path-srlgs-list* [usage]
| +---rw usage identityref
| +---rw values* srlg
+---rw path-srlgs-names
| +---rw path-srlgs-name* [usage]
| +---rw usage identityref
| +---rw names* string
+---rw disjointness? te-path-disjointness
+---rw optimizations
+---rw (algorithm)?
| +---:(metric) {path-optimization-metric}?
| | +---rw optimization-metric* [metric-type]
| | | +---rw metric-type
| | | | identityref
| | +---rw weight?
| | | uint8
| | +---rw explicit-route-exclude-objects
| | | +---rw route-object-exclude-object*
| | | | [index]
| | | +---rw index
| | | | uint32
| | +---rw (type)?
| | | +---:(numbered-node-hop)
| | | | +---rw numbered-node-hop
| | | | | +---rw node-id te-node-id
| | | | | +---rw hop-type? te-hop-type
| | | +---:(numbered-link-hop)
| | | | +---rw numbered-link-hop
| | | | | +---rw link-tp-id te-tp-id

```

```

+---rw hop-type?
| te-hop-type
+---rw direction?
| te-link-direction
+---:(unnumbered-link-hop)
+---rw unnumbered-link-hop
+---rw link-tp-id te-tp-id
+---rw node-id
| te-node-id
+---rw hop-type?
| te-hop-type
+---rw direction?
| te-link-direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number
| inet:as-number
+---rw hop-type?
| te-hop-type
+---:(label)
+---rw label-hop
+---rw te-label
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic?
| | rt-
types:generalized-label
| +---rw direction?
| | te-label-direction
+---:(srlg)
+---rw srlg
| +---rw srlg? uint32
+---rw explicit-route-include-objects
+---rw route-object-include-object*
| [index]
+---rw index
| uint32
+---rw (type)?
+---:(numbered-node-hop)
+---rw numbered-node-hop
| +---rw node-id te-node-id

```

```

+---rw hop-type? te-hop-type
+---:(numbered-link-hop)
| +---rw numbered-link-hop
| +---rw link-tp-id te-tp-id
| +---rw hop-type?
| |
| te-hop-type
| +---rw direction?
| te-link-direction
+---:(unnumbered-link-hop)
| +---rw unnumbered-link-hop
| +---rw link-tp-id te-tp-id
| +---rw node-id
| |
| te-node-id
| +---rw hop-type?
| |
| te-hop-type
| +---rw direction?
| te-link-direction
+---:(as-number)
| +---rw as-number-hop
| +---rw as-number
| |
| inet:as-number
| +---rw hop-type?
| te-hop-type
+---:(label)
| +---rw label-hop
| +---rw te-label
| +---rw (technology)?
| +---:(generic)
| +---rw generic?
| rt-
types:generalized-label
|
| +---rw direction?
| te-label-direction
+---rw tiebreakers
+---rw tiebreaker* [tiebreaker-type]
+---rw tiebreaker-type identityref
+---:(objective-function)
| {path-optimization-objective-function}?
+---rw objective-function
+---rw objective-function-type? identityref
+---ro path-properties

```

```

+--ro path-metric* [metric-type]
| +--ro metric-type identityref
| +--ro accumulative-value? uint64
+--ro path-affinities-values
| +--ro path-affinities-value* [usage]
| +--ro usage identityref
| +--ro value? admin-groups
+--ro path-affinity-names
| +--ro path-affinity-name* [usage]
| +--ro usage identityref
| +--ro affinity-name* [name]
| +--ro name string
+--ro path-srlgs-lists
| +--ro path-srlgs-list* [usage]
| +--ro usage identityref
| +--ro values* srlg
+--ro path-srlgs-names
| +--ro path-srlgs-name* [usage]
| +--ro usage identityref
| +--ro names* string
+--ro path-route-objects
| +--ro path-route-object* [index]
| +--ro index uint32
| +--ro (type)?
| +--:(numbered-node-hop)
| +--ro numbered-node-hop
| +--ro node-id te-node-id
| +--ro hop-type? te-hop-type
| +--:(numbered-link-hop)
| +--ro numbered-link-hop
| +--ro link-tp-id te-tp-id
| +--ro hop-type? te-hop-type
| +--ro direction? te-link-direction
| +--:(unnumbered-link-hop)
| +--ro unnumbered-link-hop
| +--ro link-tp-id te-tp-id
| +--ro node-id te-node-id
| +--ro hop-type? te-hop-type
| +--ro direction? te-link-direction
| +--:(as-number)
| +--ro as-number-hop

```

|       |  |  |  |                            |                          |                       |
|-------|--|--|--|----------------------------|--------------------------|-----------------------|
|       |  |  |  |                            | +--ro as-number          | inet:as-number        |
|       |  |  |  |                            | +--ro hop-type?          | te-hop-type           |
|       |  |  |  | +---:(label)               |                          |                       |
|       |  |  |  |                            | +--ro label-hop          |                       |
|       |  |  |  |                            | +--ro te-label           |                       |
|       |  |  |  |                            | +--ro (technology)?      |                       |
|       |  |  |  |                            | +---:(generic)           |                       |
|       |  |  |  |                            | +--ro generic?           |                       |
|       |  |  |  |                            |                          | rt-types:generalized- |
| label |  |  |  |                            |                          |                       |
|       |  |  |  |                            | +--ro direction?         |                       |
|       |  |  |  |                            |                          | te-label-direction    |
|       |  |  |  | +--rw connectivity-matrix* | [id]                     |                       |
|       |  |  |  | +--rw id                   |                          | uint32                |
|       |  |  |  | +--rw from                 |                          |                       |
|       |  |  |  |                            | +--rw tp-ref?            | leafref               |
|       |  |  |  |                            | +--rw label-restrictions |                       |
|       |  |  |  |                            | +--rw label-restriction* | [index]               |
|       |  |  |  |                            | +--rw restriction?       | enumeration           |
|       |  |  |  |                            | +--rw index              | uint32                |
|       |  |  |  |                            | +--rw label-start        |                       |
|       |  |  |  |                            | +--rw te-label           |                       |
|       |  |  |  |                            | +--rw (technology)?      |                       |
|       |  |  |  |                            | +---:(generic)           |                       |
|       |  |  |  |                            | +--rw generic?           |                       |
|       |  |  |  |                            |                          | rt-types:generalized- |
| label |  |  |  |                            |                          |                       |
|       |  |  |  |                            | +--rw direction?         |                       |
|       |  |  |  |                            |                          | te-label-direction    |
|       |  |  |  | +--rw label-end            |                          |                       |
|       |  |  |  |                            | +--rw te-label           |                       |
|       |  |  |  |                            | +--rw (technology)?      |                       |
|       |  |  |  |                            | +---:(generic)           |                       |
|       |  |  |  |                            | +--rw generic?           |                       |
|       |  |  |  |                            |                          | rt-types:generalized- |
| label |  |  |  |                            |                          |                       |
|       |  |  |  |                            | +--rw direction?         |                       |
|       |  |  |  |                            |                          | te-label-direction    |
|       |  |  |  | +--rw label-step           |                          |                       |
|       |  |  |  |                            | +--rw (technology)?      |                       |
|       |  |  |  |                            | +---:(generic)           |                       |





```

+--rw numbered-node-hop
+---rw node-id te-node-id
+---rw hop-type? te-hop-type
+---:(numbered-link-hop)
+---rw numbered-link-hop
+---rw link-tp-id te-tp-id
+---rw hop-type? te-hop-type
+---rw direction?
+---rw te-link-direction
+---:(unnumbered-link-hop)
+---rw unnumbered-link-hop
+---rw link-tp-id te-tp-id
+---rw node-id te-node-id
+---rw hop-type? te-hop-type
+---rw direction?
+---rw te-link-direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number inet:as-number
+---rw hop-type? te-hop-type
+---:(label)
+---rw label-hop
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw rt-
+---rw direction?
+---rw te-label-direction
+---rw backup-path* [index]
+---rw index uint32
+---rw network-ref?
+---rw -> /nw:networks/network/network-id
+---rw path-element* [path-element-id]
+---rw path-element-id uint32
+---rw (type)?
+---:(numbered-node-hop)
+---rw numbered-node-hop
+---rw node-id te-node-id
+---rw hop-type? te-hop-type

```

```

+---:(numbered-link-hop)
+---rw numbered-link-hop
+---rw link-tp-id te-tp-id
+---rw hop-type? te-hop-type
+---rw direction?
+---rw te-link-direction
+---:(unnumbered-link-hop)
+---rw unnumbered-link-hop
+---rw link-tp-id te-tp-id
+---rw node-id te-node-id
+---rw hop-type? te-hop-type
+---rw direction?
+---rw te-link-direction
+---:(as-number)
+---rw as-number-hop
+---rw as-number inet:as-number
+---rw hop-type? te-hop-type
+---:(label)
+---rw label-hop
+---rw te-label
+---rw (technology)?
+---:(generic)
+---rw generic?
+---rw rt-
types:generalized-label
+---rw direction?
+---rw te-label-direction
+---rw protection-type? identityref
+---rw tunnel-termination-points
+---rw source? binary
+---rw destination? binary
+---rw tunnels
+---rw sharing? boolean
+---rw tunnel* [tunnel-name]
+---rw tunnel-name string
+---rw sharing? boolean
+---rw path-constraints
+---rw te-bandwidth
+---rw (technology)?
+---:(generic)
+---rw generic? te-bandwidth

```

```

+--rw link-protection? identityref
+--rw setup-priority? uint8
+--rw hold-priority? uint8
+--rw signaling-type? identityref
+--rw path-metric-bounds
| +--rw path-metric-bound* [metric-type]
| | +--rw metric-type identityref
| | +--rw upper-bound? uint64
+--rw path-affinities-values
| +--rw path-affinities-value* [usage]
| | +--rw usage identityref
| | +--rw value? admin-groups
+--rw path-affinity-names
| +--rw path-affinity-name* [usage]
| | +--rw usage identityref
| | +--rw affinity-name* [name]
| | | +--rw name string
+--rw path-srlgs-lists
| +--rw path-srlgs-list* [usage]
| | +--rw usage identityref
| | +--rw values* srlg
+--rw path-srlgs-names
| +--rw path-srlgs-name* [usage]
| | +--rw usage identityref
| | +--rw names* string
+--rw disjointness?
| te-path-disjointness
+--rw optimizations
| +--rw (algorithm)?
| | +--:(metric) {path-optimization-metric}?
| | | +--rw optimization-metric* [metric-type]
| | | | +--rw metric-type
| | | | | identityref
| | | | +--rw weight?
| | | | | uint8
| | | | +--rw explicit-route-exclude-objects
| | | | | +--rw route-object-exclude-object*
| | | | | | [index]
| | | | | | +--rw index
| | | | | | | uint32
| | | | +--rw (type)?

```

|                         |  |  |  |  |  |                            |
|-------------------------|--|--|--|--|--|----------------------------|
|                         |  |  |  |  |  | +--:(numbered-node-hop)    |
|                         |  |  |  |  |  | +---rw numbered-node-hop   |
|                         |  |  |  |  |  | +---rw node-id             |
|                         |  |  |  |  |  | te-node-id                 |
|                         |  |  |  |  |  | +---rw hop-type?           |
|                         |  |  |  |  |  | te-hop-type                |
|                         |  |  |  |  |  | +--:(numbered-link-hop)    |
|                         |  |  |  |  |  | +---rw numbered-link-hop   |
|                         |  |  |  |  |  | +---rw link-tp-id          |
|                         |  |  |  |  |  | te-tp-id                   |
|                         |  |  |  |  |  | +---rw hop-type?           |
|                         |  |  |  |  |  | te-hop-type                |
|                         |  |  |  |  |  | +---rw direction?          |
|                         |  |  |  |  |  | te-link-direction          |
|                         |  |  |  |  |  | +--:(unnumbered-link-hop)  |
|                         |  |  |  |  |  | +---rw unnumbered-link-hop |
|                         |  |  |  |  |  | +---rw link-tp-id          |
|                         |  |  |  |  |  | te-tp-id                   |
|                         |  |  |  |  |  | +---rw node-id             |
|                         |  |  |  |  |  | te-node-id                 |
|                         |  |  |  |  |  | +---rw hop-type?           |
|                         |  |  |  |  |  | te-hop-type                |
|                         |  |  |  |  |  | +---rw direction?          |
|                         |  |  |  |  |  | te-link-direction          |
|                         |  |  |  |  |  | +--:(as-number)            |
|                         |  |  |  |  |  | +---rw as-number-hop       |
|                         |  |  |  |  |  | +---rw as-number           |
|                         |  |  |  |  |  | inet:as-number             |
|                         |  |  |  |  |  | +---rw hop-type?           |
|                         |  |  |  |  |  | te-hop-type                |
|                         |  |  |  |  |  | +--:(label)                |
|                         |  |  |  |  |  | +---rw label-hop           |
|                         |  |  |  |  |  | +---rw te-label            |
|                         |  |  |  |  |  | +---rw (technology)?       |
|                         |  |  |  |  |  | +--:(generic)              |
|                         |  |  |  |  |  | +---rw generic?            |
|                         |  |  |  |  |  | rt-                        |
| types:generalized-label |  |  |  |  |  |                            |
|                         |  |  |  |  |  | +---rw direction?          |
| direction               |  |  |  |  |  | te-label-                  |

```

+--:(srlg)
 +--rw srlg
 +--rw srlg? uint32
+--rw explicit-route-include-objects
 +--rw route-object-include-object*
 [index]
 +--rw index
 | uint32
 +--rw (type)?
 +--:(numbered-node-hop)
 +--rw numbered-node-hop
 +--rw node-id
 | te-node-id
 +--rw hop-type?
 | te-hop-type
 +--:(numbered-link-hop)
 +--rw numbered-link-hop
 +--rw link-tp-id
 | te-tp-id
 +--rw hop-type?
 | te-hop-type
 +--rw direction?
 | te-link-direction
 +--:(unnumbered-link-hop)
 +--rw unnumbered-link-hop
 +--rw link-tp-id
 | te-tp-id
 +--rw node-id
 | te-node-id
 +--rw hop-type?
 | te-hop-type
 +--rw direction?
 | te-link-direction
 +--:(as-number)
 +--rw as-number-hop
 +--rw as-number
 | inet:as-number
 +--rw hop-type?
 | te-hop-type
 +--:(label)
 +--rw label-hop

```

```

types:generalized-label
direction
function}?

+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-

+--rw direction?
te-label-

+--rw tiebreakers
+--rw tiebreaker* [tiebreaker-type]
+--rw tiebreaker-type identityref
+--:(objective-function)
{path-optimization-objective-

+--rw objective-function
+--rw objective-function-type?
identityref

+--ro path-properties
+--ro path-metric* [metric-type]
| +--ro metric-type identityref
| +--ro accumulative-value? uint64
+--ro path-affinities-values
+--ro path-affinities-value* [usage]
+--ro usage identityref
+--ro value? admin-groups
+--ro path-affinity-names
+--ro path-affinity-name* [usage]
+--ro usage identityref
+--ro affinity-name* [name]
+--ro name string
+--ro path-srlgs-lists
+--ro path-srlgs-list* [usage]
+--ro usage identityref
+--ro values* srlg
+--ro path-srlgs-names
+--ro path-srlgs-name* [usage]
+--ro usage identityref
+--ro names* string
+--ro path-route-objects
+--ro path-route-object* [index]

```

```

+--ro index uint32
+--ro (type)?
 +--:(numbered-node-hop)
 +--ro numbered-node-hop
 +--ro node-id te-node-id
 +--ro hop-type? te-hop-type
 +--:(numbered-link-hop)
 +--ro numbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro hop-type? te-hop-type
 +--ro direction?
 te-link-direction
 +--:(unnumbered-link-hop)
 +--ro unnumbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro node-id te-node-id
 +--ro hop-type? te-hop-type
 +--ro direction?
 te-link-direction
 +--:(as-number)
 +--ro as-number-hop
 +--ro as-number inet:as-number
 +--ro hop-type? te-hop-type
 +--:(label)
 +--ro label-hop
 +--ro te-label
 +--ro (technology)?
 +--:(generic)
 +--ro generic?
 rt-
 +--ro direction?
 te-label-direction
types:generalized-label
+--rw domain-id? uint32
+--rw is-abstract? empty
+--rw name? string
+--rw signaling-address* inet:ip-address
+--rw underlay-topology {te-topology-hierarchy}?
 +--rw network-ref? -> /nw:networks/network/network-id
+--ro oper-status? te-types:te-oper-status
+--ro geolocation

```

```

 | +---ro altitude? int64
 | +---ro latitude? geographic-coordinate-degree
 | +---ro longitude? geographic-coordinate-degree
+---ro is-multi-access-dr? empty
+---ro information-source? te-info-source
+---ro information-source-instance? string
+---ro information-source-state
 | +---ro credibility-preference? uint16
 | +---ro logical-network-element? string
 | +---ro network-instance? string
 | +---ro topology
 | +---ro node-ref? leafref
 | +---ro network-ref? -> /nw:networks/network/network-id
+---ro information-source-entry*
 | [information-source information-source-instance]
 | +---ro information-source te-info-source
 | +---ro information-source-instance string
 | +---ro information-source-state
 | +---ro credibility-preference? uint16
 | +---ro logical-network-element? string
 | +---ro network-instance? string
 | +---ro topology
 | +---ro node-ref? leafref
 | +---ro network-ref? -> /nw:networks/network/network-id
+---ro connectivity-matrices
 | +---ro number-of-entries? uint16
 | +---ro label-restrictions
 | +---ro label-restriction* [index]
 | +---ro restriction? enumeration
 | +---ro index uint32
 | +---ro label-start
 | +---ro te-label
 | +---ro (technology)?
 | +---:(generic)
 | +---ro generic?
 | rt-types:generalized-label
 | +---ro direction? te-label-direction
 | +---ro label-end
 | +---ro te-label
 | +---ro (technology)?

```



```

+---:(generic)
+---ro generic?
+---ro rt-types:generalized-label
+---ro direction? te-label-direction
+---ro label-step
+---ro (technology)?
+---:(generic)
+---ro generic? int32
+---ro range-bitmap? yang:hex-string
+---ro is-allowed? boolean
+---ro underlay {te-topology-hierarchy}?
+---ro enabled? boolean
+---ro primary-path
+---ro network-ref?
+---ro -> /nw:networks/network/network-id
+---ro path-element* [path-element-id]
+---ro path-element-id uint32
+---ro (type)?
+---:(numbered-node-hop)
+---ro numbered-node-hop
+---ro node-id te-node-id
+---ro hop-type? te-hop-type
+---:(numbered-link-hop)
+---ro numbered-link-hop
+---ro link-tp-id te-tp-id
+---ro hop-type? te-hop-type
+---ro direction? te-link-direction
+---:(unnumbered-link-hop)
+---ro unnumbered-link-hop
+---ro link-tp-id te-tp-id
+---ro node-id te-node-id
+---ro hop-type? te-hop-type
+---ro direction? te-link-direction
+---:(as-number)
+---ro as-number-hop
+---ro as-number inet:as-number
+---ro hop-type? te-hop-type
+---:(label)
+---ro label-hop
+---ro te-label
+---ro (technology)?

```

|       |  |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|-------|--|--|--|--|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  |  |  | <pre> +--:(generic)   +--ro generic?     rt-types:generalized- </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| label |  |  |  |  | <pre> +--ro direction?   te-label-direction +--ro backup-path* [index]   +--ro index          uint32   +--ro network-ref?       -&gt; /nw:networks/network/network-id   +--ro path-element* [path-element-id]     +--ro path-element-id          uint32     +--ro (type)?       +--:(numbered-node-hop)         +--ro numbered-node-hop           +--ro node-id      te-node-id           +--ro hop-type?    te-hop-type       +--:(numbered-link-hop)         +--ro numbered-link-hop           +--ro link-tp-id    te-tp-id           +--ro hop-type?    te-hop-type           +--ro direction?   te-link-direction       +--:(unnumbered-link-hop)         +--ro unnumbered-link-hop           +--ro link-tp-id    te-tp-id           +--ro node-id      te-node-id           +--ro hop-type?    te-hop-type           +--ro direction?   te-link-direction       +--:(as-number)         +--ro as-number-hop           +--ro as-number    inet:as-number           +--ro hop-type?    te-hop-type       +--:(label)         +--ro label-hop           +--ro te-label             +--ro (technology)?               +--:(generic)                 +--ro generic?                   rt-types:generalized- </pre> |
| label |  |  |  |  | <pre> +--ro direction? </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

```

| te-label-direction
+--ro protection-type? identityref
+--ro tunnel-termination-points
| +--ro source? binary
| +--ro destination? binary
+--ro tunnels
| +--ro sharing? boolean
| +--ro tunnel* [tunnel-name]
| +--ro tunnel-name string
| +--ro sharing? boolean
+--ro path-constraints
| +--ro te-bandwidth
| +--ro (technology)?
| +--:(generic)
| +--ro generic? te-bandwidth
+--ro link-protection? identityref
+--ro setup-priority? uint8
+--ro hold-priority? uint8
+--ro signaling-type? identityref
+--ro path-metric-bounds
| +--ro path-metric-bound* [metric-type]
| +--ro metric-type identityref
| +--ro upper-bound? uint64
+--ro path-affinities-values
| +--ro path-affinities-value* [usage]
| +--ro usage identityref
| +--ro value? admin-groups
+--ro path-affinity-names
| +--ro path-affinity-name* [usage]
| +--ro usage identityref
| +--ro affinity-name* [name]
| +--ro name string
+--ro path-srlgs-lists
| +--ro path-srlgs-list* [usage]
| +--ro usage identityref
| +--ro values* srlg
+--ro path-srlgs-names
| +--ro path-srlgs-name* [usage]
| +--ro usage identityref
| +--ro names* string
+--ro disjointness? te-path-disjointness

```

```

+--ro optimizations
 +--ro (algorithm)?
 +--:(metric) {path-optimization-metric}?
 +--ro optimization-metric* [metric-type]
 +--ro metric-type
 | identityref
 +--ro weight?
 | uint8
 +--ro explicit-route-exclude-objects
 +--ro route-object-exclude-object*
 [index]
 +--ro index
 | uint32
 +--ro (type)?
 +--:(numbered-node-hop)
 +--ro numbered-node-hop
 +--ro node-id te-node-id
 +--ro hop-type? te-hop-type
 +--:(numbered-link-hop)
 +--ro numbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro hop-type?
 | te-hop-type
 +--ro direction?
 te-link-direction
 +--:(unnumbered-link-hop)
 +--ro unnumbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro node-id
 | te-node-id
 +--ro hop-type?
 | te-hop-type
 +--ro direction?
 te-link-direction
 +--:(as-number)
 +--ro as-number-hop
 +--ro as-number
 | inet:as-number
 +--ro hop-type?
 te-hop-type
 +--:(label)

```

```

types:generalized-label
 +---ro label-hop
 +---ro te-label
 +---ro (technology)?
 |
 +---:(generic)
 +---ro generic?
 rt-

 +---ro direction?
 te-label-direction

+---:(srlg)
 +---ro srlg
 +---ro srlg? uint32

+---ro explicit-route-include-objects
 +---ro route-object-include-object*
 [index]
 +---ro index
 |
 uint32

+---ro (type)?
 +---:(numbered-node-hop)
 |
 +---ro numbered-node-hop
 +---ro node-id te-node-id
 +---ro hop-type? te-hop-type

 +---:(numbered-link-hop)
 +---ro numbered-link-hop
 +---ro link-tp-id te-tp-id
 +---ro hop-type?
 |
 te-hop-type
 +---ro direction?
 te-link-direction

 +---:(unnumbered-link-hop)
 +---ro unnumbered-link-hop
 +---ro link-tp-id te-tp-id
 +---ro node-id
 |
 te-node-id
 +---ro hop-type?
 |
 te-hop-type
 +---ro direction?
 te-link-direction

 +---:(as-number)
 +---ro as-number-hop
 +---ro as-number
```

```

| | inet:as-number
| | +--ro hop-type?
| | te-hop-type
| | +---:(label)
| | +--ro label-hop
| | +--ro te-label
| | +--ro (technology)?
| | +---:(generic)
| | +--ro generic?
| | rt-
types:generalized-label
| | +--ro direction?
| | te-label-direction
| | +--ro tiebreakers
| | +--ro tiebreaker* [tiebreaker-type]
| | +--ro tiebreaker-type identityref
+---:(objective-function)
| {path-optimization-objective-function}?
| +--ro objective-function
| +--ro objective-function-type? identityref
+--ro path-properties
| +--ro path-metric* [metric-type]
| | +--ro metric-type identityref
| | +--ro accumulative-value? uint64
+--ro path-affinities-values
| +--ro path-affinities-value* [usage]
| | +--ro usage identityref
| | +--ro value? admin-groups
+--ro path-affinity-names
| +--ro path-affinity-name* [usage]
| | +--ro usage identityref
| | +--ro affinity-name* [name]
| | +--ro name string
+--ro path-srlgs-lists
| +--ro path-srlgs-list* [usage]
| | +--ro usage identityref
| | +--ro values* srlg
+--ro path-srlgs-names
| +--ro path-srlgs-name* [usage]
| | +--ro usage identityref
| | +--ro names* string

```

|       |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------|--|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  | <pre> +--ro path-route-objects   +--ro path-route-object* [index]     +--ro index                               uint32     +--ro (type)?       +--:(numbered-node-hop)         +--ro numbered-node-hop           +--ro node-id       te-node-id           +--ro hop-type?     te-hop-type       +--:(numbered-link-hop)         +--ro numbered-link-hop           +--ro link-tp-id     te-tp-id           +--ro hop-type?     te-hop-type           +--ro direction?    te-link-direction       +--:(unnumbered-link-hop)         +--ro unnumbered-link-hop           +--ro link-tp-id     te-tp-id           +--ro node-id       te-node-id           +--ro hop-type?     te-hop-type           +--ro direction?    te-link-direction       +--:(as-number)         +--ro as-number-hop           +--ro as-number     inet:as-number           +--ro hop-type?     te-hop-type       +--:(label)         +--ro label-hop           +--ro te-label             +--ro (technology)?               +--:(generic)                 +--ro generic?                   rt-types:generalized- </pre> |
| label |  |  | <pre>           +--ro direction?             te-label-direction +--ro connectivity-matrix* [id]   +--ro id                               uint32   +--ro from     +--ro tp-ref?                       leafref     +--ro label-restrictions       +--ro label-restriction* [index]         +--ro restriction?             enumeration         +--ro index                     uint32 </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

|       |  |  |                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                |
|-------|--|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  |                                                                                                                                                                                                                                                                                                                                                                     | <pre> +--ro label-start     +--ro te-label         +--ro (technology)?             +--:(generic)                 +--ro generic?                     rt-types:generalized- </pre>                                               |
| label |  |  |                                                                                                                                                                                                                                                                                                                                                                     | <pre>     +--ro direction?         te-label-direction +--ro label-end     +--ro te-label         +--ro (technology)?             +--:(generic)                 +--ro generic?                     rt-types:generalized- </pre> |
| label |  |  |                                                                                                                                                                                                                                                                                                                                                                     | <pre>     +--ro direction?         te-label-direction +--ro label-step     +--ro (technology)?         +--:(generic)             +--ro generic?   int32 +--ro range-bitmap?   yang:hex-string </pre>                           |
|       |  |  | <pre> +--ro to +--ro tp-ref?           leafref +--ro label-restrictions     +--ro label-restriction* [index]         +--ro restriction?   enumeration         +--ro index         uint32 +--ro label-start     +--ro te-label         +--ro (technology)?             +--:(generic)                 +--ro generic?                     rt-types:generalized- </pre> |                                                                                                                                                                                                                                |
| label |  |  |                                                                                                                                                                                                                                                                                                                                                                     | <pre>     +--ro direction?         te-label-direction +--ro label-end     +--ro te-label         +--ro (technology)? </pre>                                                                                                    |



|       |  |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-------|--|--|--|--|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  |  |  | <pre>       +---:(generic)         +---ro generic?           rt-types:generalized- </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| label |  |  |  |  | <pre>       +---ro direction?         te-label-direction     +---ro label-step       +---ro (technology)?         +---:(generic)           +---ro generic?    int32         +---ro range-bitmap? yang:hex-string     +---ro is-allowed?      boolean     +---ro underlay {te-topology-hierarchy}?       +---ro enabled?      boolean       +---ro primary-path         +---ro network-ref?             -&gt; /nw:networks/network/network-id         +---ro path-element* [path-element-id]           +---ro path-element-id      uint32           +---ro (type)?             +---:(numbered-node-hop)               +---ro numbered-node-hop                 +---ro node-id      te-node-id                 +---ro hop-type?    te-hop-type             +---:(numbered-link-hop)               +---ro numbered-link-hop                 +---ro link-tp-id    te-tp-id                 +---ro hop-type?    te-hop-type                 +---ro direction?                   te-link-direction             +---:(unnumbered-link-hop)               +---ro unnumbered-link-hop                 +---ro link-tp-id    te-tp-id                 +---ro node-id      te-node-id                 +---ro hop-type?    te-hop-type                 +---ro direction?                   te-link-direction             +---:(as-number)               +---ro as-number-hop                 +---ro as-number    inet:as-number                 +---ro hop-type?    te-hop-type </pre> |

|                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| types:generalized-label | <pre> +--:(label)   +--ro label-hop     +--ro te-label       +--ro (technology)?         +--:(generic)           +--ro generic?             rt-            +--ro direction?             te-label-direction +--ro backup-path* [index]   +--ro index          uint32   +--ro network-ref?       -&gt; /nw:networks/network/network-id +--ro path-element* [path-element-id]   +--ro path-element-id          uint32   +--ro (type)?     +--:(numbered-node-hop)       +--ro numbered-node-hop         +--ro node-id      te-node-id         +--ro hop-type?    te-hop-type     +--:(numbered-link-hop)       +--ro numbered-link-hop         +--ro link-tp-id    te-tp-id         +--ro hop-type?    te-hop-type         +--ro direction?           te-link-direction     +--:(unnumbered-link-hop)       +--ro unnumbered-link-hop         +--ro link-tp-id    te-tp-id         +--ro node-id      te-node-id         +--ro hop-type?    te-hop-type         +--ro direction?           te-link-direction     +--:(as-number)       +--ro as-number-hop         +--ro as-number      inet:as-number         +--ro hop-type?      te-hop-type     +--:(label)       +--ro label-hop         +--ro te-label </pre> |
|-------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

```

types:generalized-label
 +--ro (technology)?
 +--:(generic)
 +--ro generic?
 rt-
 +--ro direction?
 te-label-direction
 +--ro protection-type?
 identityref
 +--ro tunnel-termination-points
 |
 | +--ro source?
 | | binary
 | +--ro destination?
 | | binary
 +--ro tunnels
 |
 | +--ro sharing?
 | | boolean
 | +--ro tunnel* [tunnel-name]
 | |
 | | +--ro tunnel-name
 | | | string
 | | +--ro sharing?
 | | | boolean
 +--ro path-constraints
 |
 | +--ro te-bandwidth
 | |
 | | +--ro (technology)?
 | | |
 | | | +--:(generic)
 | | | |
 | | | | +--ro generic?
 | | | | | te-bandwidth
 +--ro link-protection?
 | identityref
 +--ro setup-priority?
 | uint8
 +--ro hold-priority?
 | uint8
 +--ro signaling-type?
 | identityref
 +--ro path-metric-bounds
 |
 | +--ro path-metric-bound* [metric-type]
 | |
 | | +--ro metric-type
 | | | identityref
 | | +--ro upper-bound?
 | | | uint64
 +--ro path-affinities-values
 |
 | +--ro path-affinities-value* [usage]
 | |
 | | +--ro usage
 | | | identityref
 | | +--ro value?
 | | | admin-groups
 +--ro path-affinity-names
 |
 | +--ro path-affinity-name* [usage]
 | |
 | | +--ro usage
 | | | identityref
 | | +--ro affinity-name* [name]
 | | |
 | | | +--ro name
 | | | | string
 +--ro path-srlgs-lists
 |
 | +--ro path-srlgs-list* [usage]
 | |
 | | +--ro usage
 | | | identityref

```

```

| +---ro values* srlg
+---ro path-srlgs-names
| +---ro path-srlgs-name* [usage]
| +---ro usage identityref
| +---ro names* string
+---ro disjointness?
| te-path-disjointness
+---ro optimizations
+---ro (algorithm)?
| +---:(metric) {path-optimization-metric}?
| | +---ro optimization-metric* [metric-type]
| | | +---ro metric-type
| | | | identityref
| | | +---ro weight?
| | | | uint8
| | | +---ro explicit-route-exclude-objects
| | | | +---ro route-object-exclude-object*
| | | | | [index]
| | | | +---ro index
| | | | | uint32
| | | | +---ro (type)?
| | | | | +---:(numbered-node-hop)
| | | | | | +---ro numbered-node-hop
| | | | | | | +---ro node-id
| | | | | | | | te-node-id
| | | | | | | +---ro hop-type?
| | | | | | | | te-hop-type
| | | | | | +---:(numbered-link-hop)
| | | | | | | +---ro numbered-link-hop
| | | | | | | | +---ro link-tp-id
| | | | | | | | | te-tp-id
| | | | | | | | +---ro hop-type?
| | | | | | | | | te-hop-type
| | | | | | | | +---ro direction?
| | | | | | | | | te-link-direction
| | | | | | +---:(unnumbered-link-hop)
| | | | | | | +---ro unnumbered-link-hop
| | | | | | | | +---ro link-tp-id
| | | | | | | | | te-tp-id
| | | | | | | +---ro node-id
| | | | | | | | te-node-id

```

[illegible]

|                         |  |  |  |  |  |                                     |
|-------------------------|--|--|--|--|--|-------------------------------------|
|                         |  |  |  |  |  | te-hop-type                         |
|                         |  |  |  |  |  | +--ro direction?                    |
|                         |  |  |  |  |  | te-link-direction                   |
|                         |  |  |  |  |  | +--:(unnumbered-link-hop)           |
|                         |  |  |  |  |  | +--ro unnumbered-link-hop           |
|                         |  |  |  |  |  | +--ro link-tp-id                    |
|                         |  |  |  |  |  | te-tp-id                            |
|                         |  |  |  |  |  | +--ro node-id                       |
|                         |  |  |  |  |  | te-node-id                          |
|                         |  |  |  |  |  | +--ro hop-type?                     |
|                         |  |  |  |  |  | te-hop-type                         |
|                         |  |  |  |  |  | +--ro direction?                    |
|                         |  |  |  |  |  | te-link-direction                   |
|                         |  |  |  |  |  | +--:(as-number)                     |
|                         |  |  |  |  |  | +--ro as-number-hop                 |
|                         |  |  |  |  |  | +--ro as-number                     |
|                         |  |  |  |  |  | inet:as-number                      |
|                         |  |  |  |  |  | +--ro hop-type?                     |
|                         |  |  |  |  |  | te-hop-type                         |
|                         |  |  |  |  |  | +--:(label)                         |
|                         |  |  |  |  |  | +--ro label-hop                     |
|                         |  |  |  |  |  | +--ro te-label                      |
|                         |  |  |  |  |  | +--ro (technology)?                 |
|                         |  |  |  |  |  | +--:(generic)                       |
|                         |  |  |  |  |  | +--ro generic?                      |
|                         |  |  |  |  |  | rt-                                 |
| types:generalized-label |  |  |  |  |  |                                     |
|                         |  |  |  |  |  | +--ro direction?                    |
|                         |  |  |  |  |  | te-label-                           |
| direction               |  |  |  |  |  |                                     |
|                         |  |  |  |  |  | +--ro tiebreakers                   |
|                         |  |  |  |  |  | +--ro tiebreaker* [tiebreaker-type] |
|                         |  |  |  |  |  | +--ro tiebreaker-type identityref   |
|                         |  |  |  |  |  | +--:(objective-function)            |
|                         |  |  |  |  |  | {path-optimization-objective-       |
| function}?}             |  |  |  |  |  |                                     |
|                         |  |  |  |  |  | +--ro objective-function            |
|                         |  |  |  |  |  | +--ro objective-function-type?      |
|                         |  |  |  |  |  | identityref                         |
|                         |  |  |  |  |  | +--ro path-properties               |
|                         |  |  |  |  |  | +--ro path-metric* [metric-type]    |

```

| +--ro metric-type identityref
| +--ro accumulative-value? uint64
+--ro path-affinities-values
| +--ro path-affinities-value* [usage]
| +--ro usage identityref
| +--ro value? admin-groups
+--ro path-affinity-names
| +--ro path-affinity-name* [usage]
| +--ro usage identityref
| +--ro affinity-name* [name]
| +--ro name string
+--ro path-srlgs-lists
| +--ro path-srlgs-list* [usage]
| +--ro usage identityref
| +--ro values* srlg
+--ro path-srlgs-names
| +--ro path-srlgs-name* [usage]
| +--ro usage identityref
| +--ro names* string
+--ro path-route-objects
| +--ro path-route-object* [index]
| +--ro index uint32
| +--ro (type)?
| +--:(numbered-node-hop)
| +--ro numbered-node-hop
| +--ro node-id te-node-id
| +--ro hop-type? te-hop-type
| +--:(numbered-link-hop)
| +--ro numbered-link-hop
| +--ro link-tp-id te-tp-id
| +--ro hop-type? te-hop-type
| +--ro direction?
| te-link-direction
| +--:(unnumbered-link-hop)
| +--ro unnumbered-link-hop
| +--ro link-tp-id te-tp-id
| +--ro node-id te-node-id
| +--ro hop-type? te-hop-type
| +--ro direction?
| te-link-direction
| +--:(as-number)

```

```

+--ro as-number-hop
+--ro as-number inet:as-number
+--ro hop-type? te-hop-type
+--:(label)
+--ro label-hop
+--ro te-label
+--ro (technology)?
+--:(generic)
+--ro generic?
rt-
types:generalized-label
+--ro direction?
te-label-direction
+--ro domain-id? uint32
+--ro is-abstract? empty
+--ro name? string
+--ro signaling-address* inet:ip-address
+--ro underlay-topology {te-topology-hierarchy}?
+--ro network-ref? -> /nw:networks/network/network-id
+--ro statistics
+--ro discontinuity-time? yang:date-and-time
+--ro node
+--ro disables? yang:counter32
+--ro enables? yang:counter32
+--ro maintenance-sets? yang:counter32
+--ro maintenance-clears? yang:counter32
+--ro modifies? yang:counter32
+--ro connectivity-matrix-entry
+--ro creates? yang:counter32
+--ro deletes? yang:counter32
+--ro disables? yang:counter32
+--ro enables? yang:counter32
+--ro modifies? yang:counter32
+--rw tunnel-termination-point* [tunnel-tp-id]
+--rw tunnel-tp-id binary
+--rw admin-status?
| te-types:te-admin-status
+--rw name? string
+--rw switching-capability? identityref
+--rw encoding? identityref
+--rw inter-layer-lock-id* uint32

```



```

+--rw protection-type? identityref
+--rw client-layer-adaptation
| +--rw switching-capability*
| | [switching-capability encoding]
| | +--rw switching-capability identityref
| | +--rw encoding identityref
| | +--rw te-bandwidth
| | | +--rw (technology)?
| | | +--:(generic)
| | | +--rw generic? te-bandwidth
+--rw local-link-connectivities
| +--rw number-of-entries? uint16
| +--rw label-restrictions
| | +--rw label-restriction* [index]
| | | +--rw restriction? enumeration
| | | +--rw index uint32
| | | +--rw label-start
| | | | +--rw te-label
| | | | | +--rw (technology)?
| | | | | +--:(generic)
| | | | | +--rw generic?
| | | | | | rt-types:generalized-label
| | | | | +--rw direction? te-label-direction
| | | +--rw label-end
| | | | +--rw te-label
| | | | | +--rw (technology)?
| | | | | +--:(generic)
| | | | | +--rw generic?
| | | | | | rt-types:generalized-label
| | | | | +--rw direction? te-label-direction
| | | +--rw label-step
| | | | +--rw (technology)?
| | | | +--:(generic)
| | | | +--rw generic? int32
| | | +--rw range-bitmap? yang:hex-string
+--rw is-allowed? boolean
+--rw underlay {te-topology-hierarchy}?
| +--rw enabled? boolean
| +--rw primary-path
| | +--rw network-ref?
| | | -> /nw:networks/network/network-id

```

|       |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------|--|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  | <pre> +--rw path-element* [path-element-id] +--rw path-element-id          uint32 +--rw (type)? +--: (numbered-node-hop)     +--rw numbered-node-hop         +--rw node-id          te-node-id         +--rw hop-type?       te-hop-type +--: (numbered-link-hop)     +--rw numbered-link-hop         +--rw link-tp-id       te-tp-id         +--rw hop-type?       te-hop-type         +--rw direction?      te-link-direction +--: (unnumbered-link-hop)     +--rw unnumbered-link-hop         +--rw link-tp-id       te-tp-id         +--rw node-id          te-node-id         +--rw hop-type?       te-hop-type         +--rw direction?      te-link-direction +--: (as-number)     +--rw as-number-hop         +--rw as-number        inet:as-number         +--rw hop-type?       te-hop-type +--: (label)     +--rw label-hop         +--rw te-label             +--rw (technology)?                 +--: (generic)                     +--rw generic?                         rt-types:generalized- </pre> |
| label |  |  | <pre> +--rw direction? +--rw te-label-direction +--rw backup-path* [index] +--rw index          uint32 +--rw network-ref?     -&gt; /nw:networks/network/network-id +--rw path-element* [path-element-id] +--rw path-element-id          uint32 +--rw (type)? +--: (numbered-node-hop)     +--rw numbered-node-hop </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |

|       |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------|--|--|--|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  |  | <pre>       +--rw node-id      te-node-id       +--rw hop-type?    te-hop-type +--:(numbered-link-hop)   +--rw numbered-link-hop     +--rw link-tp-id     te-tp-id     +--rw hop-type?      te-hop-type     +--rw direction?     te-link-direction +--:(unnumbered-link-hop)   +--rw unnumbered-link-hop     +--rw link-tp-id     te-tp-id     +--rw node-id        te-node-id     +--rw hop-type?      te-hop-type     +--rw direction?     te-link-direction +--:(as-number)   +--rw as-number-hop     +--rw as-number      inet:as-number     +--rw hop-type?      te-hop-type +--:(label)   +--rw label-hop     +--rw te-label       +--rw (technology)?         +--:(generic)           +--rw generic?             rt-types:generalized- </pre> |
| label |  |  |  | <pre>       +--rw direction?         te-label-direction +--rw protection-type?      identityref +--rw tunnel-termination-points   +--rw source?             binary   +--rw destination?        binary +--rw tunnels   +--rw sharing?            boolean   +--rw tunnel* [tunnel-name]     +--rw tunnel-name       string     +--rw sharing?          boolean +--rw path-constraints   +--rw te-bandwidth     +--rw (technology)?       +--:(generic)         +--rw generic?      te-bandwidth </pre>                                                                                                                                                                                                                                                 |

```

+--rw link-protection? identityref
+--rw setup-priority? uint8
+--rw hold-priority? uint8
+--rw signaling-type? identityref
+--rw path-metric-bounds
| +--rw path-metric-bound* [metric-type]
| | +--rw metric-type identityref
| | +--rw upper-bound? uint64
+--rw path-affinities-values
| +--rw path-affinities-value* [usage]
| | +--rw usage identityref
| | +--rw value? admin-groups
+--rw path-affinity-names
| +--rw path-affinity-name* [usage]
| | +--rw usage identityref
| | +--rw affinity-name* [name]
| | | +--rw name string
+--rw path-srlgs-lists
| +--rw path-srlgs-list* [usage]
| | +--rw usage identityref
| | +--rw values* srlg
+--rw path-srlgs-names
| +--rw path-srlgs-name* [usage]
| | +--rw usage identityref
| | +--rw names* string
+--rw disjointness? te-path-disjointness
+--rw optimizations
| +--rw (algorithm)?
| | +--:(metric) {path-optimization-metric}?
| | | +--rw optimization-metric* [metric-type]
| | | | +--rw metric-type
| | | | | identityref
| | | | +--rw weight?
| | | | | uint8
| | | +--rw explicit-route-exclude-objects
| | | | +--rw route-object-exclude-object*
| | | | | [index]
| | | | | +--rw index
| | | | | | uint32
| | | +--rw (type)?
| | | | +--:(numbered-node-hop)

```

|  |  |  |  |  |                                      |                             |
|--|--|--|--|--|--------------------------------------|-----------------------------|
|  |  |  |  |  |                                      | +--rw numbered-node-hop     |
|  |  |  |  |  |                                      | +--rw node-id te-node-id    |
|  |  |  |  |  |                                      | +--rw hop-type? te-hop-type |
|  |  |  |  |  | +---:(numbered-link-hop)             |                             |
|  |  |  |  |  |                                      | +--rw numbered-link-hop     |
|  |  |  |  |  |                                      | +--rw link-tp-id te-tp-id   |
|  |  |  |  |  |                                      | +--rw hop-type?             |
|  |  |  |  |  |                                      | te-hop-type                 |
|  |  |  |  |  |                                      | +--rw direction?            |
|  |  |  |  |  |                                      | te-link-direction           |
|  |  |  |  |  | +---:(unnumbered-link-hop)           |                             |
|  |  |  |  |  |                                      | +--rw unnumbered-link-hop   |
|  |  |  |  |  |                                      | +--rw link-tp-id te-tp-id   |
|  |  |  |  |  |                                      | +--rw node-id               |
|  |  |  |  |  |                                      | te-node-id                  |
|  |  |  |  |  |                                      | +--rw hop-type?             |
|  |  |  |  |  |                                      | te-hop-type                 |
|  |  |  |  |  |                                      | +--rw direction?            |
|  |  |  |  |  |                                      | te-link-direction           |
|  |  |  |  |  | +---:(as-number)                     |                             |
|  |  |  |  |  |                                      | +--rw as-number-hop         |
|  |  |  |  |  |                                      | +--rw as-number             |
|  |  |  |  |  |                                      | inet:as-number              |
|  |  |  |  |  |                                      | +--rw hop-type?             |
|  |  |  |  |  |                                      | te-hop-type                 |
|  |  |  |  |  | +---:(label)                         |                             |
|  |  |  |  |  |                                      | +--rw label-hop             |
|  |  |  |  |  |                                      | +--rw te-label              |
|  |  |  |  |  |                                      | +--rw (technology)?         |
|  |  |  |  |  |                                      | +---:(generic)              |
|  |  |  |  |  |                                      | +--rw generic?              |
|  |  |  |  |  |                                      | rt-                         |
|  |  |  |  |  |                                      |                             |
|  |  |  |  |  |                                      | +--rw direction?            |
|  |  |  |  |  |                                      | te-label-direction          |
|  |  |  |  |  | +---:(srlg)                          |                             |
|  |  |  |  |  |                                      | +--rw srlg                  |
|  |  |  |  |  |                                      | +--rw srlg? uint32          |
|  |  |  |  |  | +--rw explicit-route-include-objects |                             |
|  |  |  |  |  | +--rw route-object-include-object*   |                             |
|  |  |  |  |  | [index]                              |                             |

|                         |  |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------|--|--|--|--|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                         |  |  |  |  | <pre> +--rw index     uint32 +--rw (type)?   +--:(numbered-node-hop)       +--rw numbered-node-hop           +--rw node-id       te-node-id           +--rw hop-type?    te-hop-type   +--:(numbered-link-hop)       +--rw numbered-link-hop           +--rw link-tp-id    te-tp-id           +--rw hop-type?                               +--rw direction?                   te-link-direction   +--:(unnumbered-link-hop)       +--rw unnumbered-link-hop           +--rw link-tp-id    te-tp-id           +--rw node-id                               +--rw hop-type?                                       +--rw direction?                       te-link-direction   +--:(as-number)       +--rw as-number-hop           +--rw as-number                               +--rw hop-type?                   te-hop-type   +--:(label)       +--rw label-hop           +--rw te-label               +--rw (technology)?                   +--:(generic)                       +--rw generic?                           rt-           +--rw direction?           te-label-direction   +--rw tiebreakers   +--rw tiebreaker* [tiebreaker-type] </pre> |
| types:generalized-label |  |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |

```

| +--rw tiebreaker-type identityref
+--:(objective-function)
| {path-optimization-objective-function}?
| +--rw objective-function
| +--rw objective-function-type? identityref
+--ro path-properties
+--ro path-metric* [metric-type]
| +--ro metric-type identityref
| +--ro accumulative-value? uint64
+--ro path-affinities-values
| +--ro path-affinities-value* [usage]
| | +--ro usage identityref
| | +--ro value? admin-groups
+--ro path-affinity-names
| +--ro path-affinity-name* [usage]
| | +--ro usage identityref
| | +--ro affinity-name* [name]
| | | +--ro name string
+--ro path-srlgs-lists
| +--ro path-srlgs-list* [usage]
| | +--ro usage identityref
| | +--ro values* srlg
+--ro path-srlgs-names
| +--ro path-srlgs-name* [usage]
| | +--ro usage identityref
| | +--ro names* string
+--ro path-route-objects
+--ro path-route-object* [index]
| +--ro index uint32
| +--ro (type)?
| | +--:(numbered-node-hop)
| | | +--ro numbered-node-hop
| | | | +--ro node-id te-node-id
| | | | +--ro hop-type? te-hop-type
| | +--:(numbered-link-hop)
| | | +--ro numbered-link-hop
| | | | +--ro link-tp-id te-tp-id
| | | | +--ro hop-type? te-hop-type
| | | | +--ro direction? te-link-direction
| | +--:(unnumbered-link-hop)
| | | +--ro unnumbered-link-hop

```

```

+--ro link-tp-id te-tp-id
+--ro node-id te-node-id
+--ro hop-type? te-hop-type
+--ro direction? te-link-direction
+--:(as-number)
+--ro as-number-hop
+--ro as-number inet:as-number
+--ro hop-type? te-hop-type
+--:(label)
+--ro label-hop
+--ro te-label
+--ro (technology)?
+--:(generic)
+--ro generic?
rt-types:generalized-

label
+--ro direction?
te-label-direction
+--rw local-link-connectivity* [link-tp-ref]
+--rw link-tp-ref
|
-> ../../../../nt:termination-point/tp-id
+--rw label-restrictions
+--rw label-restriction* [index]
+--rw restriction? enumeration
+--rw index uint32
+--rw label-start
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-types:generalized-label
+--rw direction? te-label-direction
+--rw label-end
+--rw te-label
+--rw (technology)?
+--:(generic)
+--rw generic?
rt-types:generalized-label
+--rw direction? te-label-direction
+--rw label-step
+--rw (technology)?

```



```

+---:(generic)
| +---rw generic? int32
| +---rw range-bitmap? yang:hex-string
+---rw is-allowed? boolean
+---rw underlay {te-topology-hierarchy}?
| +---rw enabled? boolean
| +---rw primary-path
| | +---rw network-ref?
| | | -> /nw:networks/network/network-id
| +---rw path-element* [path-element-id]
| | +---rw path-element-id uint32
| +---rw (type)?
| | +---:(numbered-node-hop)
| | | +---rw numbered-node-hop
| | | | +---rw node-id te-node-id
| | | | +---rw hop-type? te-hop-type
| | +---:(numbered-link-hop)
| | | +---rw numbered-link-hop
| | | | +---rw link-tp-id te-tp-id
| | | | +---rw hop-type? te-hop-type
| | | | +---rw direction?
| | | | | te-link-direction
| | +---:(unnumbered-link-hop)
| | | +---rw unnumbered-link-hop
| | | | +---rw link-tp-id te-tp-id
| | | | +---rw node-id te-node-id
| | | | +---rw hop-type? te-hop-type
| | | | +---rw direction?
| | | | | te-link-direction
| +---:(as-number)
| | +---rw as-number-hop
| | | +---rw as-number inet:as-number
| | | +---rw hop-type? te-hop-type
| +---:(label)
| | +---rw label-hop
| | | +---rw te-label
| | | | +---rw (technology)?
| | | | | +---:(generic)
| | | | | | +---rw generic?
| | | | | | | rt-
types:generalized-label

```

```

| +--rw direction?
| te-label-direction
+--rw backup-path* [index]
| +--rw index uint32
| +--rw network-ref?
| | -> /nw:networks/network/network-id
+--rw path-element* [path-element-id]
| +--rw path-element-id uint32
| +--rw (type)?
| | +--:(numbered-node-hop)
| | | +--rw numbered-node-hop
| | | | +--rw node-id te-node-id
| | | | +--rw hop-type? te-hop-type
| | +--:(numbered-link-hop)
| | | +--rw numbered-link-hop
| | | | +--rw link-tp-id te-tp-id
| | | | +--rw hop-type? te-hop-type
| | | | +--rw direction?
| | | | te-link-direction
| | +--:(unnumbered-link-hop)
| | | +--rw unnumbered-link-hop
| | | | +--rw link-tp-id te-tp-id
| | | | +--rw node-id te-node-id
| | | | +--rw hop-type? te-hop-type
| | | | +--rw direction?
| | | | te-link-direction
| | +--:(as-number)
| | | +--rw as-number-hop
| | | | +--rw as-number inet:as-number
| | | | +--rw hop-type? te-hop-type
| | +--:(label)
| | | +--rw label-hop
| | | | +--rw te-label
| | | | | +--rw (technology)?
| | | | | | +--:(generic)
| | | | | | | +--rw generic?
| | | | | | | rt-
| | | | | | | +--rw direction?
| | | | | | | te-label-direction
+--rw protection-type? identityref

```

types:generalized-label

```

+--rw tunnel-termination-points
| +--rw source? binary
| +--rw destination? binary
+--rw tunnels
| +--rw sharing? boolean
| +--rw tunnel* [tunnel-name]
| +--rw tunnel-name string
| +--rw sharing? boolean
+--rw path-constraints
+--rw te-bandwidth
| +--rw (technology)?
| +--:(generic)
| +--rw generic? te-bandwidth
+--rw link-protection? identityref
+--rw setup-priority? uint8
+--rw hold-priority? uint8
+--rw signaling-type? identityref
+--rw path-metric-bounds
| +--rw path-metric-bound* [metric-type]
| +--rw metric-type identityref
| +--rw upper-bound? uint64
+--rw path-affinities-values
| +--rw path-affinities-value* [usage]
| +--rw usage identityref
| +--rw value? admin-groups
+--rw path-affinity-names
| +--rw path-affinity-name* [usage]
| +--rw usage identityref
| +--rw affinity-name* [name]
| +--rw name string
+--rw path-srlgs-lists
| +--rw path-srlgs-list* [usage]
| +--rw usage identityref
| +--rw values* srlg
+--rw path-srlgs-names
| +--rw path-srlgs-name* [usage]
| +--rw usage identityref
| +--rw names* string
+--rw disjointness?
| te-path-disjointness
+--rw optimizations

```

```

+--rw (algorithm)?
 +--:(metric) {path-optimization-metric}?
 +--rw optimization-metric* [metric-type]
 +--rw metric-type
 | identityref
 +--rw weight?
 | uint8
 +--rw explicit-route-exclude-objects
 +--rw route-object-exclude-object*
 [index]
 +--rw index
 | uint32
 +--rw (type)?
 +--:(numbered-node-hop)
 +--rw numbered-node-hop
 +--rw node-id
 | te-node-id
 +--rw hop-type?
 | te-hop-type
 +--:(numbered-link-hop)
 +--rw numbered-link-hop
 +--rw link-tp-id
 | te-tp-id
 +--rw hop-type?
 | te-hop-type
 +--rw direction?
 | te-link-direction
 +--:(unnumbered-link-hop)
 +--rw unnumbered-link-hop
 +--rw link-tp-id
 | te-tp-id
 +--rw node-id
 | te-node-id
 +--rw hop-type?
 | te-hop-type
 +--rw direction?
 | te-link-direction
 +--:(as-number)
 +--rw as-number-hop
 +--rw as-number
 | inet:as-number

```

|                         |  |  |                                      |                     |                  |
|-------------------------|--|--|--------------------------------------|---------------------|------------------|
|                         |  |  |                                      |                     | +--rw hop-type?  |
|                         |  |  |                                      |                     | te-hop-type      |
|                         |  |  |                                      | +--:(label)         |                  |
|                         |  |  |                                      | +--rw label-hop     |                  |
|                         |  |  |                                      | +--rw te-label      |                  |
|                         |  |  |                                      | +--rw (technology)? |                  |
|                         |  |  |                                      | +--:(generic)       |                  |
|                         |  |  |                                      | +--rw generic?      |                  |
|                         |  |  |                                      |                     | rt-              |
| types:generalized-label |  |  |                                      |                     |                  |
|                         |  |  |                                      |                     | +--rw direction? |
|                         |  |  |                                      |                     | te-label-        |
| direction               |  |  |                                      |                     |                  |
|                         |  |  |                                      | +--:(srlg)          |                  |
|                         |  |  |                                      | +--rw srlg          |                  |
|                         |  |  |                                      | +--rw srlg? uint32  |                  |
|                         |  |  | +--rw explicit-route-include-objects |                     |                  |
|                         |  |  | +--rw route-object-include-object*   |                     |                  |
|                         |  |  | [index]                              |                     |                  |
|                         |  |  | +--rw index                          |                     |                  |
|                         |  |  | uint32                               |                     |                  |
|                         |  |  | +--rw (type)?                        |                     |                  |
|                         |  |  | +--:(numbered-node-hop)              |                     |                  |
|                         |  |  | +--rw numbered-node-hop              |                     |                  |
|                         |  |  | +--rw node-id                        |                     |                  |
|                         |  |  | te-node-id                           |                     |                  |
|                         |  |  | +--rw hop-type?                      |                     |                  |
|                         |  |  | te-hop-type                          |                     |                  |
|                         |  |  | +--:(numbered-link-hop)              |                     |                  |
|                         |  |  | +--rw numbered-link-hop              |                     |                  |
|                         |  |  | +--rw link-tp-id                     |                     |                  |
|                         |  |  | te-tp-id                             |                     |                  |
|                         |  |  | +--rw hop-type?                      |                     |                  |
|                         |  |  | te-hop-type                          |                     |                  |
|                         |  |  | +--rw direction?                     |                     |                  |
|                         |  |  | te-link-direction                    |                     |                  |
|                         |  |  | +--:(unnumbered-link-hop)            |                     |                  |
|                         |  |  | +--rw unnumbered-link-hop            |                     |                  |
|                         |  |  | +--rw link-tp-id                     |                     |                  |
|                         |  |  | te-tp-id                             |                     |                  |
|                         |  |  | +--rw node-id                        |                     |                  |

|                         |  |  |  |  |  |                                      |
|-------------------------|--|--|--|--|--|--------------------------------------|
|                         |  |  |  |  |  | te-node-id                           |
|                         |  |  |  |  |  | +--rw hop-type?                      |
|                         |  |  |  |  |  | te-hop-type                          |
|                         |  |  |  |  |  | +--rw direction?                     |
|                         |  |  |  |  |  | te-link-direction                    |
|                         |  |  |  |  |  | +---:(as-number)                     |
|                         |  |  |  |  |  | +--rw as-number-hop                  |
|                         |  |  |  |  |  | +--rw as-number                      |
|                         |  |  |  |  |  | inet:as-number                       |
|                         |  |  |  |  |  | +--rw hop-type?                      |
|                         |  |  |  |  |  | te-hop-type                          |
|                         |  |  |  |  |  | +---:(label)                         |
|                         |  |  |  |  |  | +--rw label-hop                      |
|                         |  |  |  |  |  | +--rw te-label                       |
|                         |  |  |  |  |  | +--rw (technology)?                  |
|                         |  |  |  |  |  | +---:(generic)                       |
|                         |  |  |  |  |  | +--rw generic?                       |
|                         |  |  |  |  |  | rt-                                  |
| types:generalized-label |  |  |  |  |  |                                      |
|                         |  |  |  |  |  | +--rw direction?                     |
| direction               |  |  |  |  |  | te-label-                            |
|                         |  |  |  |  |  |                                      |
|                         |  |  |  |  |  | +--rw tiebreakers                    |
|                         |  |  |  |  |  | +--rw tiebreaker* [tiebreaker-type]  |
|                         |  |  |  |  |  | +--rw tiebreaker-type identityref    |
|                         |  |  |  |  |  | +---:(objective-function)            |
|                         |  |  |  |  |  | {path-optimization-objective-        |
| function}?              |  |  |  |  |  |                                      |
|                         |  |  |  |  |  | +--rw objective-function             |
|                         |  |  |  |  |  | +--rw objective-function-type?       |
|                         |  |  |  |  |  | identityref                          |
|                         |  |  |  |  |  | +--ro path-properties                |
|                         |  |  |  |  |  | +--ro path-metric* [metric-type]     |
|                         |  |  |  |  |  | +--ro metric-type identityref        |
|                         |  |  |  |  |  | +--ro accumulative-value? uint64     |
|                         |  |  |  |  |  | +--ro path-affinities-values         |
|                         |  |  |  |  |  | +--ro path-affinities-value* [usage] |
|                         |  |  |  |  |  | +--ro usage identityref              |
|                         |  |  |  |  |  | +--ro value? admin-groups            |
|                         |  |  |  |  |  | +--ro path-affinity-names            |
|                         |  |  |  |  |  | +--ro path-affinity-name* [usage]    |

```

 +--ro usage identityref
 +--ro affinity-name* [name]
 +--ro name string
+--ro path-srlgs-lists
 +--ro path-srlgs-list* [usage]
 +--ro usage identityref
 +--ro values* srlg
+--ro path-srlgs-names
 +--ro path-srlgs-name* [usage]
 +--ro usage identityref
 +--ro names* string
+--ro path-route-objects
 +--ro path-route-object* [index]
 +--ro index uint32
 +--ro (type)?
 +--:(numbered-node-hop)
 +--ro numbered-node-hop
 +--ro node-id te-node-id
 +--ro hop-type? te-hop-type
 +--:(numbered-link-hop)
 +--ro numbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro hop-type? te-hop-type
 +--ro direction?
 te-link-direction
 +--:(unnumbered-link-hop)
 +--ro unnumbered-link-hop
 +--ro link-tp-id te-tp-id
 +--ro node-id te-node-id
 +--ro hop-type? te-hop-type
 +--ro direction?
 te-link-direction
 +--:(as-number)
 +--ro as-number-hop
 +--ro as-number inet:as-number
 +--ro hop-type? te-hop-type
 +--:(label)
 +--ro label-hop
 +--ro te-label
 +--ro (technology)?
 +--:(generic)

```

```

| | +--ro generic?
| | rt-
types:generalized-label
| | +--ro direction?
| | te-label-direction
| +--ro oper-status?
| | te-types:te-oper-status
| +--ro geolocation
| | +--ro altitude? int64
| | +--ro latitude? geographic-coordinate-degree
| | +--ro longitude? geographic-coordinate-degree
| +--ro statistics
| | +--ro discontinuity-time? yang:date-and-time
| | +--ro tunnel-termination-point
| | | +--ro disables? yang:counter32
| | | +--ro enables? yang:counter32
| | | +--ro maintenance-clears? yang:counter32
| | | +--ro maintenance-sets? yang:counter32
| | | +--ro modifies? yang:counter32
| | | +--ro downs? yang:counter32
| | | +--ro ups? yang:counter32
| | | +--ro in-service-clears? yang:counter32
| | | +--ro in-service-sets? yang:counter32
| | +--ro local-link-connectivity
| | | +--ro creates? yang:counter32
| | | +--ro deletes? yang:counter32
| | | +--ro disables? yang:counter32
| | | +--ro enables? yang:counter32
| | | +--ro modifies? yang:counter32
| +--rw supporting-tunnel-termination-point*
| | [node-ref tunnel-tp-ref]
| | +--rw node-ref inet:uri
| | +--rw tunnel-tp-ref binary
augment /nw:networks/nw:network/nt:link:
+--rw te!
| +--rw (bundle-stack-level)?
| | +--:(bundle)
| | | +--rw bundled-links
| | | | +--rw bundled-link* [sequence]
| | | | | +--rw sequence uint32
| | | | | +--rw src-tp-ref? leafref

```



```

| +---rw des-tp-ref? leafref
+---:(component)
| +---rw component-links
| | +---rw component-link* [sequence]
| | | +---rw sequence uint32
| | | +---rw src-interface-ref? string
| | | +---rw des-interface-ref? string
+---rw te-link-template*
| -> ../../../../te/templates/link-template/name
| {template}?
+---rw te-link-attributes
| +---rw access-type?
| | te-types:te-link-access-type
+---rw external-domain
| +---rw network-ref?
| | -> /nw:networks/network/network-id
+---rw remote-te-node-id? te-types:te-node-id
| +---rw remote-te-link-tp-id? te-types:te-tp-id
+---rw is-abstract? empty
+---rw name? string
+---rw underlay {te-topology-hierarchy}?
| +---rw enabled? boolean
+---rw primary-path
| +---rw network-ref?
| | -> /nw:networks/network/network-id
+---rw path-element* [path-element-id]
| +---rw path-element-id uint32
| +---rw (type)?
| | +---:(numbered-node-hop)
| | | +---rw numbered-node-hop
| | | | +---rw node-id te-node-id
| | | | +---rw hop-type? te-hop-type
| | | +---:(numbered-link-hop)
| | | | +---rw numbered-link-hop
| | | | | +---rw link-tp-id te-tp-id
| | | | | +---rw hop-type? te-hop-type
| | | | | +---rw direction? te-link-direction
| | | +---:(unnumbered-link-hop)
| | | | +---rw unnumbered-link-hop
| | | | | +---rw link-tp-id te-tp-id
| | | | | +---rw node-id te-node-id

```

|       |  |  |  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-------|--|--|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|       |  |  |  | <pre>       +--rw hop-type?      te-hop-type       +--rw direction?    te-link-direction +--:(as-number)       +--rw as-number-hop       +--rw as-number      inet:as-number       +--rw hop-type?      te-hop-type +--:(label)       +--rw label-hop       +--rw te-label           +--rw (technology)?               +--:(generic)                   +--rw generic?                       rt-types:generalized- </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| label |  |  |  | <pre>           +--rw direction?               te-label-direction +--rw backup-path* [index] +--rw index          uint32 +--rw network-ref?     -&gt; /nw:networks/network/network-id +--rw path-element* [path-element-id] +--rw path-element-id          uint32 +--rw (type)? +--:(numbered-node-hop)     +--rw numbered-node-hop         +--rw node-id      te-node-id         +--rw hop-type?    te-hop-type +--:(numbered-link-hop)     +--rw numbered-link-hop         +--rw link-tp-id    te-tp-id         +--rw hop-type?    te-hop-type         +--rw direction?   te-link-direction +--:(unnumbered-link-hop)     +--rw unnumbered-link-hop         +--rw link-tp-id    te-tp-id         +--rw node-id      te-node-id         +--rw hop-type?    te-hop-type         +--rw direction?   te-link-direction +--:(as-number)     +--rw as-number-hop         +--rw as-number      inet:as-number </pre> |

```

| +--rw hop-type? te-hop-type
+---:(label)
| +--rw label-hop
| +--rw te-label
| +--rw (technology)?
| | +--:(generic)
| | +--rw generic?
| | rt-types:generalized-
label
| +--rw direction?
| | te-label-direction
+---rw protection-type? identityref
+---rw tunnel-termination-points
| +--rw source? binary
| +--rw destination? binary
+---rw tunnels
| +--rw sharing? boolean
| +--rw tunnel* [tunnel-name]
| | +--rw tunnel-name string
| | +--rw sharing? boolean
+---rw admin-status?
| te-types:te-admin-status
+---rw link-index? uint64
+---rw administrative-group?
| te-types:admin-groups
+---rw interface-switching-capability*
| [switching-capability encoding]
| +--rw switching-capability identityref
| +--rw encoding identityref
| +--rw max-lsp-bandwidth* [priority]
| | +--rw priority uint8
| | +--rw te-bandwidth
| | | +--rw (technology)?
| | | +--:(generic)
| | | +--rw generic? te-bandwidth
+---rw label-restrictions
| +--rw label-restriction* [index]
| | +--rw restriction? enumeration
| | +--rw index uint32
| +--rw label-start
| | +--rw te-label

```

```

 +---rw (technology)?
 | +---:(generic)
 | +---rw generic?
 | rt-types:generalized-label
 +---rw direction? te-label-direction
+---rw label-end
| +---rw te-label
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic?
| | rt-types:generalized-label
| +---rw direction? te-label-direction
+---rw label-step
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic? int32
+---rw range-bitmap? yang:hex-string
+---rw link-protection-type? identityref
+---rw max-link-bandwidth
| +---rw te-bandwidth
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic? te-bandwidth
+---rw max-resv-link-bandwidth
| +---rw te-bandwidth
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic? te-bandwidth
+---rw unreserved-bandwidth* [priority]
| +---rw priority uint8
| +---rw te-bandwidth
| +---rw (technology)?
| | +---:(generic)
| | +---rw generic? te-bandwidth
+---rw te-default-metric? uint32
+---rw te-delay-metric? uint32
+---rw te-igp-metric? uint32
+---rw te-srlgs
| +---rw value* te-types:srlg
+---rw te-nsrlgs {nsrlg}?
| +---rw id* uint32

```

```

+--ro oper-status? te-types:te-oper-status
+--ro is-transitional? empty
+--ro information-source? te-info-source
+--ro information-source-instance? string
+--ro information-source-state
| +--ro credibility-preference? uint16
| +--ro logical-network-element? string
| +--ro network-instance? string
| +--ro topology
| +--ro link-ref? leafref
| +--ro network-ref? -> /nw:networks/network/network-id
+--ro information-source-entry*
| [information-source information-source-instance]
| +--ro information-source te-info-source
| +--ro information-source-instance string
| +--ro information-source-state
| +--ro credibility-preference? uint16
| +--ro logical-network-element? string
| +--ro network-instance? string
| +--ro topology
| +--ro link-ref? leafref
| +--ro network-ref? -> /nw:networks/network/network-id
+--ro link-index? uint64
+--ro administrative-group?
| te-types:admin-groups
+--ro interface-switching-capability*
| [switching-capability encoding]
| +--ro switching-capability identityref
| +--ro encoding identityref
| +--ro max-lsp-bandwidth* [priority]
| +--ro priority uint8
| +--ro te-bandwidth
| +--ro (technology)?
| +--:(generic)
| +--ro generic? te-bandwidth
+--ro label-restrictions
| +--ro label-restriction* [index]
| +--ro restriction? enumeration
| +--ro index uint32
| +--ro label-start

```

```

 +--ro te-label
 +--ro (technology)?
 +--:(generic)
 +--ro generic?
 rt-types:generalized-label
 +--ro direction? te-label-direction
 +--ro label-end
 +--ro te-label
 +--ro (technology)?
 +--:(generic)
 +--ro generic?
 rt-types:generalized-label
 +--ro direction? te-label-direction
 +--ro label-step
 +--ro (technology)?
 +--:(generic)
 +--ro generic? int32
 +--ro range-bitmap? yang:hex-string
+--ro link-protection-type? identityref
+--ro max-link-bandwidth
 +--ro te-bandwidth
 +--ro (technology)?
 +--:(generic)
 +--ro generic? te-bandwidth
+--ro max-resv-link-bandwidth
 +--ro te-bandwidth
 +--ro (technology)?
 +--:(generic)
 +--ro generic? te-bandwidth
+--ro unreserved-bandwidth* [priority]
 +--ro priority uint8
 +--ro te-bandwidth
 +--ro (technology)?
 +--:(generic)
 +--ro generic? te-bandwidth
+--ro te-default-metric? uint32
+--ro te-delay-metric? uint32
+--ro te-igp-metric? uint32
+--ro te-srlgs
 +--ro value* te-types:srlg
+--ro te-nsrlgs {nsrlg}?

```

```

 | +---ro id* uint32
+---ro recovery
 | +---ro restoration-status? te-types:te-recovery-status
 | +---ro protection-status? te-types:te-recovery-status
+---ro underlay {te-topology-hierarchy}?
 | +---ro dynamic? boolean
 | +---ro committed? boolean
+---ro statistics
 | +---ro discontinuity-time? yang:date-and-time
 | +---ro disables? yang:counter32
 | +---ro enables? yang:counter32
 | +---ro maintenance-clears? yang:counter32
 | +---ro maintenance-sets? yang:counter32
 | +---ro modifies? yang:counter32
 | +---ro downs? yang:counter32
 | +---ro ups? yang:counter32
 | +---ro fault-clears? yang:counter32
 | +---ro fault-detects? yang:counter32
 | +---ro protection-switches? yang:counter32
 | +---ro protection-reverts? yang:counter32
 | +---ro restoration-failures? yang:counter32
 | +---ro restoration-starts? yang:counter32
 | +---ro restoration-successes? yang:counter32
 | +---ro restoration-reversion-failures? yang:counter32
 | +---ro restoration-reversion-starts? yang:counter32
 | +---ro restoration-reversion-successes? yang:counter32
augment /nw:networks/nw:network/nw:node/nt:termination-point:
+---rw te-tp-id? te-types:te-tp-id
+---rw te!
 +---rw admin-status?
 | te-types:te-admin-status
 +---rw name? string
 +---rw interface-switching-capability*
 | [switching-capability encoding]
 | +---rw switching-capability identityref
 | +---rw encoding identityref
 | +---rw max-lsp-bandwidth* [priority]
 | | +---rw priority uint8
 | | +---rw te-bandwidth
 | | | +---rw (technology)?
 | | | | +---:(generic)

```

```
| +--rw generic? te-bandwidth
+--rw inter-domain-plug-id? binary
+--rw inter-layer-lock-id* uint32
+--ro oper-status?
| te-types:te-oper-status
+--ro geolocation
 +--ro altitude? int64
 +--ro latitude? geographic-coordinate-degree
 +--ro longitude? geographic-coordinate-degree
```



## Appendix B. Companion YANG Model for Non-NMDA Compliant Implementations

The YANG module `ietf-te-topology` defined in this document is designed to be used in conjunction with implementations that support the Network Management Datastore Architecture (NMDA) defined in [RFC8342]. In order to allow implementations to use the model even in cases when NMDA is not supported, the following companion module `ietf-te-topology-state` is defined as a state model, which mirrors the module `ietf-te-topology` defined earlier in this document. However, all data nodes in the companion module are non-configurable, to represent the applied configuration or the derived operational states.

The companion module, `ietf-te-topology-state`, is redundant and SHOULD NOT be supported by implementations that support NMDA.

As the structure of the module `ietf-te-topology-state` mirrors that of the module `ietf-te-topology`. The YANG tree of the module `ietf-te-topology-state` is not depicted separately.

## B.1. TE Topology State YANG Module

This module references [RFC6001], [RFC8345], and [I-D.ietf-teas-yang-te-types].

```
<CODE BEGINS> file "ietf-te-topology-state@2019-02-07.yang"
module ietf-te-topology-state {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te-topology-state";

 prefix "tet-s";

 import ietf-te-types {
 prefix "te-types";
 reference
 "I-D.ietf-teas-yang-te-types: Traffic Engineering Common YANG
 Types";
 }

 import ietf-te-topology {
 prefix "tet";
 }

 import ietf-network-state {
```

```
 prefix "nw-s";
 reference "RFC 8345: A YANG Data Model for Network Topologies";
}

import ietf-network-topology-state {
 prefix "nt-s";
 reference "RFC 8345: A YANG Data Model for Network Topologies";
}

organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

contact
 "WG Web: <http://tools.ietf.org/wg/teas/>
 WG List: <mailto:teas@ietf.org>

 Editor: Xufeng Liu
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 Editor: Himanshu Shah
 <mailto:hshah@ciena.com>

 Editor: Oscar Gonzalez De Dios
 <mailto:oscar.gonzalezdedios@telefonica.com>";

description
 "TE topology state model.

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 authors of the code. All rights reserved.
```

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This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices."

```
revision "2019-02-07" {
 description "Initial revision";
 reference "RFC XXXX: YANG Data Model for TE Topologies";
 // RFC Ed.: replace XXXX with actual RFC number and remove
 // this note
}

/*
 * Groupings
 */
grouping te-node-connectivity-matrix-attributes {
 description
 "Termination point references of a connectivity matrix entry.";
 container from {
 description
 "Reference to source link termination point.";
 leaf tp-ref {
 type leafref {
 path "../..//../..//../nt-s:termination-point/nt-s:tp-id";
 }
 description
 "Relative reference to a termination point.";
 }
 uses te-types:label-set-info;
 }
 container to {
 description
 "Reference to destination link termination point.";
 leaf tp-ref {
 type leafref {
 path "../..//../..//../nt-s:termination-point/nt-s:tp-id";
 }
 }
 }
}
```

```
 }
 description
 "Relative reference to a termination point.";
 }
 uses te-types:label-set-info;
}
uses tet:connectivity-matrix-entry-path-attributes;
} // te-node-connectivity-matrix-attributes

grouping te-node-tunnel-termination-point-llc-list {
 description
 "Local link connectivity list of a tunnel termination
 point on a TE node.";
 list local-link-connectivity {
 key "link-tp-ref";
 description
 "The termination capabilities between
 tunnel-termination-point and link termination-point.
 The capability information can be used to compute
 the tunnel path.
 The Interface Adjustment Capability Descriptors (IACD)
 (defined in RFC 6001) on each link-tp can be derived from
 this local-link-connectivity list.";
 reference
 "RFC 6001: Generalized MPLS (GMPLS) Protocol Extensions
 for Multi-Layer and Multi-Region Networks (MLN/MRN).";

 leaf link-tp-ref {
 type leafref {
 path "../.../.../.../nt-s:termination-point/nt-s:tp-id";
 }
 description
 "Link termination point.";
 }
 uses te-types:label-set-info;
 uses tet:connectivity-matrix-entry-path-attributes;
 } // local-link-connectivity
} // te-node-tunnel-termination-point-config

/*
 * Data nodes
```

```
*/
augment "/nw-s:networks/nw-s:network/nw-s:network-types" {
 description
 "Introduce new network type for TE topology.";
 container te-topology {
 presence "Indicates TE topology.";
 description
 "Its presence identifies the TE topology type.";
 }
}

augment "/nw-s:networks" {
 description
 "Augmentation parameters for TE topologies.";
 uses tet:te-topologies-augment;
}

augment "/nw-s:networks/nw-s:network" {
 when "nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE topology.";
 uses tet:te-topology-augment;
}

augment "/nw-s:networks/nw-s:network/nw-s:node" {
 when "../nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE at node level.";
 leaf te-node-id {
 type te-types:te-node-id;
 description
 "The identifier of a node in the TE topology.
 A node is specific to a topology to which it belongs.";
 }
}
```

```
 }
 container te {
 must "../te-node-id" {
 description
 "te-node-id is mandatory.";
 }
 must "count(..nw-s:supporting-node)<=1" {
 description
 "For a node in a TE topology, there cannot be more
 than 1 supporting node. If multiple nodes are abstracted,
 the underlay-topology is used.";
 }
 presence "TE support.";
 description
 "Indicates TE support.";
 uses tet:te-node-augment;
 } // te
 }

 augment "/nw-s:networks/nw-s:network/nt-s:link" {
 when "../nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE at link level.";
 container te {
 must "count(..nt-s:supporting-link)<=1" {
 description
 "For a link in a TE topology, there cannot be more
 than 1 supporting link. If one or more link paths are
 abstracted, the underlay is used.";
 }
 presence "TE support.";
 description
 "Indicates TE support.";
 uses tet:te-link-augment;
 } // te
 }
}
```

```
augment "/nw-s:networks/nw-s:network/nw-s:node/"
 + "nt-s:termination-point" {
 when "../..nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Configuration parameters for TE at termination point level.";
 uses tet:te-termination-point-augment;
 }

augment
 "/nw-s:networks/nw-s:network/nt-s:link/te/bundle-stack-level/"
 + "bundle/bundled-links/bundled-link" {
 when "../..nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE link bundled link.";
 leaf src-tp-ref {
 type leafref {
 path "../..nw-s:node[nw-s:node-id = "
 + "current()../..nt-s:source/"
 + "nt-s:source-node]/"
 + "nt-s:termination-point/nt-s:tp-id";
 require-instance true;
 }
 description
 "Reference to another TE termination point on the
 same source node.";
 }
 leaf des-tp-ref {
 type leafref {
 path "../..nw-s:node[nw-s:node-id = "
 + "current()../..nt-s:destination/"
 + "nt-s:dest-node]/"
 + "nt-s:termination-point/nt-s:tp-id";
 require-instance true;
 }
 }
 }
```

```
 }
 description
 "Reference to another TE termination point on the
 same destination node.";
 }
}

augment
 "/nw-s:networks/nw-s:network/nw-s:node/te/"
+ "information-source-entry/connectivity-matrices/"
+ "connectivity-matrix" {
 when "../..../nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE node connectivity-matrix.";
 uses te-node-connectivity-matrix-attributes;
}

augment
 "/nw-s:networks/nw-s:network/nw-s:node/te/te-node-attributes/"
+ "connectivity-matrices/connectivity-matrix" {
 when "../..../nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
 }
 description
 "Augment TE node connectivity-matrix.";
 uses te-node-connectivity-matrix-attributes;
}

augment
 "/nw-s:networks/nw-s:network/nw-s:node/te/"
+ "tunnel-termination-point/local-link-connectivities" {
 when "../..../nw-s:network-types/tet-s:te-topology" {
 description
 "Augmentation parameters apply only for networks with
 TE topology type.";
```



```
 }
 description
 "Augment TE node tunnel termination point LLCs
 (Local Link Connectivities).";
 uses te-node-tunnel-termination-point-llc-list;
 }
}
<CODE ENDS>
```

## Appendix C. Example: YANG Model for Technology Specific Augmentations

This section provides an example YANG module to define a technology specific TE topology model for the example-topology described in Section 6.

```
module example-topology {
 yang-version 1.1;

 namespace "http://example.com/example-topology";
 prefix "ex-topo";

 import ietf-network {
 prefix "nw";
 }

 import ietf-network-topology {
 prefix "nt";
 }

 import ietf-te-topology {
 prefix "tet";
 }

 organization
 "Example Organization";
 contact
 "Editor: Example Author";

 description
 "This module defines a topology data model for the example
 technology.";

 revision 2018-06-15 {
 description
 "Initial revision.";
 reference
 "Example reference.";
 }

 /*
 * Data nodes
```

```
*/
augment "/nw:networks/nw:network/nw:network-types/"
+ "tet:te-topology" {
 description
 "Augment network types to define example topology type.";
 container example-topology {
 presence
 "Introduce new network type for example topology.";
 description
 "Its presence identifies the example topology type.";
 }
}

augment "/nw:networks/nw:network/tet:te" {
 when "../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment network topology.";
 container attributes {
 description "Attributes for example technology.";
 leaf attribute-1 {
 type uint8;
 description "Attribute 1 for example technology.";
 }
 }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes" {
 when "../..nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment node attributes.";
 container attributes {
 description "Attributes for example technology.";
 }
}
```

```
 leaf attribute-2 {
 type uint8;
 description "Attribute 2 for example technology.";
 }
 }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment node connectivity matrices.";
 container attributes {
 description "Attributes for example technology.";
 leaf attribute-3 {
 type uint8;
 description "Attribute 3 for example technology.";
 }
 }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment node connectivity matrix.";
 container attributes {
 description "Attributes for example technology.";
 leaf attribute-3 {
 type uint8;
 description "Attribute 3 for example technology.";
 }
 }
}
```

```
 }
 }

 augment "/nw:networks/nw:network/nw:node/tet:te/"
 + "tet:tunnel-termination-point" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment tunnel termination point.";
 container attributes {
 description "Attributes for example technology.";
 leaf attribute-4 {
 type uint8;
 description "Attribute 4 for example technology.";
 }
 }
 }
}

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
 + "tet:te" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 description "Augment link termination point.";
 container attributes {
 description "Attributes for example technology.";
 leaf attribute-5 {
 type uint8;
 description "Attribute 5 for example technology.";
 }
 }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
 + "tet:te-link-attributes" {
```

```
when "../../../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
description "Augment link attributes.";
container attributes {
 description "Attributes for example technology.";
 leaf attribute-6 {
 type uint8;
 description "Attribute 6 for example technology.";
 }
}
}

/*
 * Augment TE bandwidth.
 */

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:max-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 case "example" {
```

```
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:max-resv-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:unreserved-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
```

```
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
 when "../..../..../..../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
 when "../..../..../..../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
}
```



```
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../..../..../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../..../..../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
}
```

```

 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:client-layer-adaptation/"
+ "tet:switching-capability/tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;

```

```
 description "Bandwidth 1 for example technology.";
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example{
```

```
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:max-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:max-resv-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
}
```

```
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
 }

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:max-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
```

```
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:max-resv-link-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
 }
 description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:unreserved-bandwidth/"
```

```
+ "tet:te-bandwidth/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
}
description "Augment TE bandwidth.";
}

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
+ "tet:te/"
+ "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
+ "tet:te-bandwidth/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf bandwidth-1 {
 type uint32;
 description "Bandwidth 1 for example technology.";
 }
 }
}
description "Augment TE bandwidth.";
}
```

```
/*
 * Augment TE label.
 */

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
 case "example" {
```



```
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}

description "Augment TE label."
}
```

```
augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
}
description "Augment TE label."
}
```

```
/* Under te-node-attributes/connectivity-matrices */
```

```
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type";
 }
case "example" {
 container example {
```

```

 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
 when "../..../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 when "../..../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
}

```

```

 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
 }

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..../nw:network-types/"

```

```
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

/* Under te-node-attributes/.../connectivity-matrix */

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when ".../..."
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}
```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}

```

```

 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../..//../..//../..//../..//../..//../..//nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..//../..//../..//../..//../..//../..//nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {

```

```

 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 when "../..//..//..//..//..//..//..//..//..//nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 when "../..//..//..//..//..//..//..//..//..//nw:network-types/"

```

```
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

/* Under information-source-entry/connectivity-matrices */

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
 when "../../../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
}
description "Augment TE label.";
}
```



```
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
 when "../../../../../../../../../../../nw:network-types/tet:te-topology/"
 + "ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 when "../../../../../../../../../../../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
}
```

```

 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..../..../..../..../..../..../..../..../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..../..../..../..../..../..../..../..../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;

```

```

 description "Label 1 for example technology.";
 }
}
description "Augment TE label.";
}

/* Under information-source-entry/.../connectivity-matrix */

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
container example {
description "Attributes for example technology.";
leaf label-1 {
type uint32;
description "Label 1 for example technology.";
}
}
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with

```

```
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
 when "../..//../..//../..//../..//../..//nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
```

```
+ "tet:te-label/tet:technology" {
when "../..../..../..../..../..../..../..../..../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../..../..../..../..../..../..../..../..../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}
```

```
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 }
 }
}
```

```
 description "Label 1 for example technology.";
 }
}
description "Augment TE label.";
}

/* Under tunnel-termination-point/local-link-connectivities */

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
container example {
description "Attributes for example technology.";
leaf label-1 {
type uint32;
description "Label 1 for example technology.";
}
}
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../..../nw:network-types/tet:te-topology/"
+ "ex-topo:example-topology" {
description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
}
```

```

case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description

```



```

 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
 when "../..//../..//../..//../..//../..//../..//nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

/* Under tunnel-termination-point/.../local-link-connectivity */

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../.../../...../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../.../../...../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
```

```

 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 }
}
}

```

```
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}

description "Augment TE label.";
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../../.../../.../../.../../.../../.../../.../../.../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type."
 }
case "example" {
 container example {
 description "Attributes for example technology."
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology."
 }
 }
}
description "Augment TE label.";
}

/* Under te-link-attributes */

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
when "../.../../.../../.../../.../../.../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
```

```
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
 when "../..//../..//../..//../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
```

```
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../nw:network-types/"
+ "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
}
case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
}
description "Augment TE label.";
}
```

```
/* Under te-link information-source-entry */

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-start/"
+ "tet:te-label/tet:technology" {
 when "../..//../..//../..//../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
 description "Augment TE label.";
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:information-source-entry/"
+ "tet:label-restrictions/tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
 when "../..//../..//../..//../nw:network-types/"
 + "tet:te-topology/ex-topo:example-topology" {
 description
 "Augmentation parameters apply only for networks with
 example topology type.";
 }
 case "example" {
 container example {
 description "Attributes for example technology.";
 leaf label-1 {
 type uint32;
 description "Label 1 for example technology.";
 }
 }
 }
}
```

```
 }
 }
 description "Augment TE label.";
}
}
```

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## A Yang Data Model for WSON Tunnel

draft-lee-ccamp-wson-tunnel-model-04.txt

### Abstract

This document provides a YANG data model for WSON TE tunnel.

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## 1. Introduction

This document provides a YANG data model for WSON tunnel model. The YANG model described in this document is a WSON technology-specific Yang Tunnel model based on the information model developed in [RFC7446] and the two encoding documents [RFC7581] and [RFC7579] that developed protocol independent encodings based on [RFC7446].

This document augments the generic TE tunnel model [TE-Tunnel].

## 2. YANG Model (Tree Structure)

module: ietf-wson-tunnel

```
augment /te:te/te:tunnels/te:tunnel:
 +--rw src-client-signal? identityref
 +--rw dst-client-signal? identityref
augment /te:te/te:tunnels/te:tunnel/te:state:
 +--ro src-client-signal? identityref
 +--ro dst-client-signal? identityref
augment /te:te/te:globals/te:named-path-constraints/te:named-path-
constraint:
 +--rw wavelength-assignment? identityref
augment /te:tunnels-rpc/te:input/te:tunnel-info/tepc:request-list:
 +---- src-client-signal? identityref
 +---- dst-client-signal? identityref
 +---- wavelength-assignment? identityref
```

### 3. TE Tunnel Model for WSON

<CODE BEGINS> file "ietf-wson-tunnel@2018-01-08.yang"

```
module ietf-wson-tunnel {
 //TODO: FIXME
 //yang-version 1.1;

 namespace "urn:ietf:params:xml:ns:yang:ietf-wson-tunnel";
 prefix "wson-tunnel";

 import ietf-te { prefix "te"; }
 import ietf-otn-types { prefix "otn-types"; }
 import ietf-te-wson-types { prefix "wson-types"; }
 import ietf-te-path-computation { prefix "tepc"; }

 organization
 "IETF CCAMP Working Group";

 contact
 "WG Web: <http://tools.ietf.org/wg/ccamp/>
 WG List: <mailto:ccamp@ietf.org>

 WG Chair: Daniele Ceccarelli
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```

```
Editor: Young Lee <leeyoung@huawei.com>
Editor: Dhruv Dhody <dhruv.ietf@gmail.com>
Editor: Ricard Vilalta <ricard.vilalta@cttc.es>;
description
 "This module defines a model for WSON Tunnel Services.";

revision "2018-01-08" {
 description
 "Updates to version 4";
 reference "version 4";
}

grouping wson-tunnel-endpoint {
 description "Parameters for OTN tunnel.";

 leaf src-client-signal {
 type identityref {
 base otn-types:client-signal;
 }
 description
 "Client signal at the source endpoint of
 the tunnel.";
 }

 leaf dst-client-signal {
 type identityref {
 base otn-types:client-signal;
 }
 description
 "Client signal at the destination endpoint of
 the tunnel.";
 }
}

grouping wson-path-constraints {
 description
 "Global named path constraints configuration
 grouping for WSON tunnel";

 leaf wavelength-assignment {
 type identityref {
 base wson-types:wavelength-assignment;
 }
 }
}
```

```
 description "Wavelength Allocation Method";
 }
}

augment "/te:te/te:tunnels/te:tunnel" {
 description
 "Augment with additional parameters required for WSON
 tunnel.";
 uses wson-tunnel-endpoint;
}

augment "/te:te/te:tunnels/te:tunnel/te:state" {
 description
 "Augment with additional parameters required for WSON
 tunnel.";
 uses wson-tunnel-endpoint;
}

augment "/te:te/te:globals/te:named-path-constraints/"
+ "te:named-path-constraint" {
 description
 "Augment with additional constraints WSON
 tunnel.";
 uses wson-path-constraints;
}

augment "/te:tunnels-rpc/te:input/te:tunnel-info/"
+ "tepc:request-list" {
 description
 "Augment with additional constraints WSON
 tunnel.";
 uses wson-tunnel-endpoint;
 uses wson-path-constraints;
}

}
```

<CODE ENDS>

#### 4. Security Considerations

The configuration, state, and action data defined in this document

are designed to be accessed via a management protocol with a secure transport layer, such as NETCONF [RFC6241]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a preconfigured subset of all available NETCONF protocol operations and content.

A number of configuration data nodes defined in this document are writable/deletable (i.e., "config true") These data nodes may be considered sensitive or vulnerable in some network environments.

## 5. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```

URI: urn:ietf:params:xml:ns:yang:ietf-wson-tunnel
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

This document registers the following YANG modules in the YANG Module

Names registry [RFC7950]:

```

name: ietf-wson-tunnel
namespace: urn:ietf:params:xml:ns:yang:ietf-wson-tunnel
reference: RFC XXXX (TDB)

```

## 6. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.



## 7. References

### 7.1. Normative References

[TE-TOPO] X. Liu, et al., "YANG Data Model for TE Topologies", work in progress: draft-ietf-teas-yang-te-topo.

### 7.2. Informative References

[RFC7446] Y. Lee, G. Bernstein, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

[RFC7579] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "General Network Element Constraint Encoding for GMPLS Controlled Networks", RFC 7579, November 2015.

[RFC7581] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, November 2015.

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Abstraction and Control of TE Networks (ACTN) Abstraction Methods  
draft-lee-teas-actn-abstraction-02

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## Abstract

Abstraction and Control of Traffic Engineering (TE) Networks (ACTN) refers to the set of virtual network operations needed to orchestrate, control and manage large-scale multi-domain TE networks, so as to facilitate network programmability, automation, and efficient resource sharing.

As the ACTN architecture considers abstraction as one of the important building blocks, this document describes a few alternatives methods of abstraction for both packet and optical networks. This is an important consideration since the choice of the abstraction method impacts protocol design and the information it carries.

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## 1. Introduction

Abstraction and Control of TE Networks (ACTN) describes a method for operating a Traffic Engineered (TE) network (such as an MPLS-TE network or a layer 1 transport network) to provide connectivity and virtual network services for customers of the TE network. The services provided can be tuned to meet the requirements (such as traffic patterns, quality, and reliability) of the applications hosted by the customers. More details about ACTN can be found in Section 2.

Abstraction is defined in [RFC7926] as:

Abstraction is the process of applying policy to the available TE information within a domain, to produce selective information that represents the potential ability to connect across the domain. Thus, abstraction does not necessarily offer all possible connectivity options, but presents a general view of potential connectivity according to the policies that determine how the domain's administrator wants to allow the domain resources to be used.

Connectivity referred to this document is TE path through a series of connected domains as used in [RFC7926].

As the ACTN architecture considers abstraction as one of the important building blocks, this document discusses a few alternatives for the methods of abstraction for both packet and optical networks. This is an important consideration since the choice of the abstraction method impacts protocol design and the information it carries.

The purpose of this document is to find a common agreement on the factors and methods of abstraction. These abstraction factors and methods may in turn impact implementations and protocol design.

## 2. Abstraction Factors in ACTN Architecture

This section provides abstraction factors in the ACTN architecture. [ACTN-Frame] describes the architecture model for ACTN including the entities (Customer Network Controller (CNC), Multi-domain Service

Coordinator (MDSC), and Physical Network Controller (PNC) and their interfaces.

The MDSC oversees the specific aspects of the different domains and builds a single abstracted end-to-end network topology in order to coordinate end-to-end path computation and path/service provisioning. In order for the MDSC to perform its coordination function, it depends on the coordination with the PNCs which are the domain-level controllers especially as to what level of domain network resource abstraction is agreed upon between the MDSC and the PNCs.

As discussed in [RFC7926], abstraction is tied with policy of the networks. For instance, per an operational policy, the PNC would not be allowed to provide any technology specific details (e.g., optical parameters for WSON) in its update. In such case, the abstraction level of the update will be in a generic nature. In order for the MDSC to get technology specific topology information from the PNC, a request/reply mechanism may be employed.

In some cases, abstraction is also tied with the controller's capability of abstraction as abstraction involves some rules and algorithms to be applied to the actual network resource information (which is also known as network topology).

[TE-Topology] describes YANG models for TE-network abstraction. [PCEP-LS] describes PCEP Link-state mechanism that also allows for transport of abstract topology in the context of Hierarchical PCE.

There are factors that may impact the choice of abstraction and presents a number of abstraction methods. It is important to understand that abstraction depends on several factors:

- The nature of underlying domain networks: Abstraction depends on the nature of the underlying domain networks. For instance, packet networks may have different level of abstraction requirements from that of optical networks. Within optical networks, WSON may have different level of abstraction requirements than the OTN networks.
- The capability of the PNC: Abstraction depends on the capability of the PNCs. As abstraction requires hiding details of the underlying resource network resource information, the PNC capability to run some internal optimization algorithm impacts the feasibility of abstraction. Some PNC may not have the ability to abstract native topology while other PNCs may have such an ability to abstract actual topology by using sophisticated algorithms.

- Scalability factor: Abstraction is a function of scalability. If the actual network resource information is of small size, then the need for abstraction would be less than the case where the native network resource information is of large size. In some cases, abstraction may not be needed at all.
- The frequency of topology updates: The proper abstraction level may depend on the frequency of topology updates and vice versa.
- The capability/nature of the MDSC: The nature of the MDSC impacts the degree/level of abstraction. If the MDSC is not capable of handling optical parameters such as those specific to OTN/WSN, then white topology abstraction may not work well.
- The confidentiality: In some cases where the PNC would like to hide key internal topological data from the MDSC, the abstraction method should consider this aspect.
- The scope of abstraction: All of the aforementioned factors are equally applicable to both the MPI (MDSC-PNC Interface) and the CMI (CNC-MDSC Interface).

[ACTN-Framework] defined the following three levels of topology abstraction and their descriptions:

- . White topology: this is a case where the PNC provides the actual network topology to the MDSC without any hiding or filtering.
- . Black topology: the entire domain network is abstracted as a single virtual node (see the definition of virtual node in [RFC7926]) with the access/egress links without disclosing any node internal connectivity information.
- . Grey topology: this abstraction level is between black topology and white topology from a granularity point of view. we may further differentiate from a perspective of how to abstract internal TE resources between the pairs of border nodes:
  - o Grey topology type A: border nodes with a TE links between them in a full mesh fashion
  - o Grey topology type B: border nodes with some internal abstracted nodes and abstracted links



### 3. Build Method of Grey Topology

This section discusses two different methods of building a grey topology:

- . Automatic generation of abstract topology by configuration (Section 3.1)
- . On-demand generation of supplementary topology via path computation request/reply (Section 3.2)

#### 3.1. Automatic generation of abstract topology by configuration

The "Automatic generation" method is based on the abstraction/summarization of the whole domain by the PNC and its advertisement on MPI interface once the abstraction level is configured. The level of abstraction advertisement can be decided based on some PNC configuration parameters (e.g. provide the potential connectivity between any PE and any ASBR in an MPLS-TE network as described in section 3.3.1)

Note that the configuration parameters for this potential topology can include available B/W, latency, or any combination of defined parameters. How to generate such tunnel information is beyond the scope of this document. Appendix A provides one example of this method for the WSON case.

Such potential topology needs to be periodically or incrementally/asynchronously updated every time that a failure, a recovery or the setup of new VNs causes a change in the characteristics of the advertised grey topology (e.g. in our previous case if due to changes in the network is it now possible to provide connectivity between a given PE and a given ASBR with a higher delay in the update).

#### 3.2. On-demand generation of supplementary topology via path compute request/reply

The "on-demand generation" of supplementary topology is to be distinguished from automatic generation of abstract topology. While abstract topology is generated and updated automatically by configuration as explained in Section 3.1., additional supplementary topology may be obtained by the MDSC via path compute request/reply mechanism. Starting with a black topology advertisement from the

PNCs, the MDSC may need additional information beyond the level of black topology from the PNCs. It is assumed that the black topology advertisement from PNCs would give the MDSC each domain's the border node/link information as described in Figure 2. Under this scenario, when the MDSC needs to allocate a new VN, the MDSC can issue a number of Path Computation requests as described in [ACTN-YANG] to different PNCs with constraints matching the VN request.

An example is provided in Figure 4, where the MDSC is requesting to setup a P2P VN between AP1 and AP2. The MDSC can use two different inter-domain links to get from Domain X to Domain Y, namely the one between ASBRX.1 and ASBRY.1 and the one between ASBRX.2 and ASBRY.2, but in order to choose the best end to end path it needs to know what domain X and Y can offer in term of connectivity and constraints between the PE nodes and the ASBR nodes.

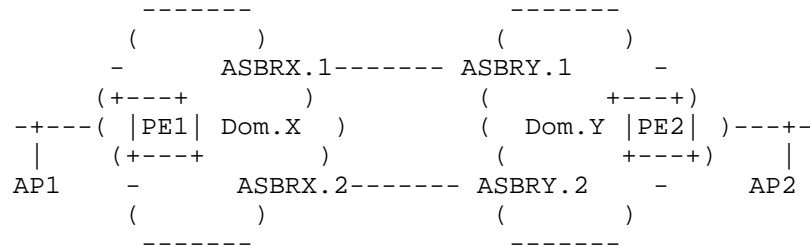


Figure 4: A multi-domain networks example

A path computation request will be issued to PNC.X asking for potential connectivity between PE1 and ASBRX.1 and between PE1 and ASBRX.2 with related objective functions and TE metric constraints. A similar request will be issued to PNC.Y and the results merged together at the MDSC to be able to compute the optimal end-to-end path including the inter domain links.

The info related to the potential connectivity may be cached by the MDSC for subsequent path computation processes or discarded, but in this case the PNCs are not requested to keep the grey topology updated.

#### 4. Protocol/Data Model Requirements

This section provides a set of requirements that may impact the way protocol/data model is designed and the information elements thereof which are carried in the protocol/data model.

It is expected that the abstraction level be negotiated between the CNC and the MDSC (i.e., the CMI) depending on the capability of the CNC. This negotiated level of abstraction on the CMI may also impact the way the MDSC and the PNCs configure and encode the abstracted topology. For example, if the CNC is capable of sophisticated technology specific operation, then this would impact the level of abstraction at the MDSC with the PNCs. On the other hand, if the CNC asks for a generic topology abstraction, then the level of abstraction at the MDSC with the PNCs can be less technology specific than the former case.

The subsequent sections provide a list of possible abstraction levels for various technology domain networks.

##### 4.1. Packet Networks

- For grey abstraction, the type of abstraction and its parameters MUST be defined and configured/negotiated.
  - o Abstraction Level 1: TE-tunnel abstraction for all (S-D) border pairs with:
    - . Maximum B/W available per Priority Level
    - . Minimum Latency
  - o Other Level (TBD)

##### 4.2. OTN Networks

For OTN networks, max bandwidth available may be per ODU 0/1/2/3 switching level or aggregated across all ODU switching levels (i.e., ODUj/k). Clearly, there is a trade-off between these two abstraction methods. Some OTN switches can switch any level of ODUs and in such case there is no need for ODU level abstraction.

- For grey abstraction, the type of abstraction and its parameters MUST be defined and configured/negotiated.
  - o Abstraction Level 1: Per ODU Switching level (i.e., ODU type and number) TE-tunnel abstraction for all (S-D) border pairs with:

- . Maximum B/W available per Priority Level
  - . Minimum Latency
- o Abstraction Level 2: Aggregated TE-tunnel abstraction for all (S-D) border pairs with:
  - . Maximum B/W available per Priority Level
  - . Minimum Latency
- o Other Level (TBD)

#### 4.3. WSON Networks

For WSON networks, max bandwidth available may be per lambda/frequency level (OCh) or aggregated across all lambda/frequency level. Per OCh level abstraction gives more detailed data to the MDSC at the expense of more information processing. Either OCh-level or aggregated level abstraction should factor in the RWA constraint (i.e., wavelength continuity) at the PNC level. This means the PNC should have this capability and advertise it as such. See the Appendix for this abstraction method.

- For grey abstraction, the type of abstraction MUST and its parameters be defined and configured/negotiated.
  - o Abstraction Level 1: Per Lambda/Frequency level TE-tunnel abstraction for all (S-D) border pairs with:
    - . Maximum B/W available per Priority Level
    - . Minimum Latency
  - o Abstraction Level 2: Aggregated TE-tunnel abstraction for all (S-D) border pairs with:
    - . Maximum B/W available per Priority Level
    - . Minimum Latency
  - o Other Level (TBD)

Examples: these examples show how to compute WSON grey topology Abstraction Level 1 and Level 2. These examples illustrate that the encoding of an abstraction topology can be impacted by the configured/negotiated abstraction level in the ACTN interfaces.

This section provides how WSON grey topology abstraction levels 1 and 2 can be computed at a PNC. These examples illustrate that the

encoding of an abstraction topology can be impacted by the configured/negotiated abstraction level at the MPI.

. Abstraction Level 1: Per Lambda/Frequency level TE-tunnel abstraction for all (S-D) border pairs:

For each (S-D) border node pair,

- 1) The concept of a lambda plane: A lambda plane is a confined optical topology with respect to a given lambda value. If an OMS link has the wavelength of the given lambda available, it is included, otherwise excluded.
- 2) Calculate the maximal flow between S and D in every lambda plane. Max flow computation is restricted to each lambda plane is for OCh wavelength continuity.
- 3) Convert each feasible lambda plane with OCh wavelength continuity to B/W equivalent encoding; Send this per lambda level encoding for (S-D) to the MDSC;

. Abstraction Level 2: Aggregated TE-tunnel abstraction for WSON for all (S-D) border pairs

For each (S-D) border node pair,

- 1) The concept of a lambda plane: A lambda plane is a confined optical topology with respect to a given lambda value. If an OMS link has the wavelength of the given lambda available, it is included, otherwise excluded.
- 2) Calculate the maximal flow between S and D in every lambda plane. Max flow computation is restricted to each lambda plane is for OCh wavelength continuity.
- 3) Add up the max flow values across all lambda planes. This is the maximal number of OCh paths that can be setup between S and D at the same time.
- 4) Convert the max number of OCh paths to B/W equivalent encoding; Send this encoding as max B/W for (S-D) to the MDSC;

## 5. Acknowledgements

We thank Adrian Farrel and Italo Busi for providing useful comments and suggestions for this draft.

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YANG models for VN & TE Performance Monitoring Telemetry and Scaling  
Intent Autonomics

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## Abstract

This document provides YANG data models that describe performance monitoring telemetry and scaling intent mechanism for TE-tunnels and Virtual Networks (VN).

The models presented in this draft allow customers to subscribe to and monitor their key performance data of their interest on the level of TE-tunnel or VN. The models also provide customers with the ability to program autonomic scaling intent mechanism on the level of TE-tunnel as well as VN.

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## 1. Introduction

The YANG model discussed in [VN] is used to operate customer-driven Virtual Networks (VNs) during the VN instantiation, VN computation, and its life-cycle service management and operations. YANG model discussed in [TE-Tunnel] is used to operate TE-tunnels during the tunnel instantiation, and its life-cycle management and operations.

The models presented in this draft allow the applications hosted by the customers to subscribe to and monitor their key performance data of their interest on the level of VN [VN] or TE-tunnel [TE-Tunnel]. The key characteristic of the models presented in this document is a top-down programmability that allows the applications hosted by the customers to subscribe to and monitor key performance data of their interest and autonomic scaling intent mechanism on the level of VN as well as TE-tunnel.

According to the classification of [RFC8309], the YANG data models presented in this document can be classified as customer service models, which is mapped to CMI (Customer Network Controller (CNC)-Multi-Domain Service Coordinator (MSDC) interface) of ACTN [RFC8453].

[RFC8233] describes key network performance data to be considered for end-to-end path computation in TE networks. Key performance indicator (KPI) is a term that describes critical performance data that may affect VN/TE-tunnel service. The services provided can be optimized to meet the requirements (such as traffic patterns, quality, and reliability) of the applications hosted by the customers.

This document provides YANG data models generically applicable to any VN/TE-Tunnel service clients to provide an ability to program their customized performance monitoring subscription and publication data models and automatic scaling in/out intent data models. These models can be utilized by a client network controller to initiate these capability to a transport network controller communicating with the client controller via a NETCONF [RFC8341] or a RESTCONF [RFC8040] interface.

The term performance monitoring being used in this document is different from the term that has been used in transport networks for many years. Performance monitoring in this document refers to subscription and publication of streaming telemetry data. Subscription is initiated by the client (e.g., CNC) while publication is provided by the network (e.g., MDSC/PNC) based on the client's subscription. As the scope of performance monitoring in this document is telemetry data on the level of client's VN or TE-tunnel, the entity interfacing the client (e.g., MDSC) has to provide VN or TE-tunnel level information. This would require controller capability to derive VN or TE-tunnel level performance data based on lower-level data collected via PM counters in the Network Elements (NE). How the controller entity derives such customized level data (i.e., VN or TE-tunnel level) is out of the scope of this document.

The data model includes configuration and state data according to the new Network Management Datastore Architecture [RFC8342].

### 1.1. Terminology

Refer to [RFC8453], [RFC7926], and [RFC8309] for the key terms used in this document.

**Key Performance Data:** This refers to a set of data the customer is interested in monitoring for their instantiated VNs or TE-tunnels. Key performance data and key performance indicators are interchangeable in this draft.

**Scaling:** This refers to the network ability to re-shape its own resources. Scale out refers to improve network performance by increasing the allocated resources, while scale in refers to decrease the allocated resources, typically because the existing resources are unnecessary.

**Scaling Intent:** To declare scaling conditions, scaling intent is used. Specifically, scaling intent refers to the intent expressed by the client that allows the client to program/configure conditions of their key performance data either for scaling out or scaling in. Various conditions can be set for scaling intent on either VN or TE-tunnel level.

**Network Autonomics:** This refers to the network automation capability that allows client to initiate scaling intent mechanisms and provides the client with the status of the adjusted network

resources based on the client's scaling intent in an automated fashion.

### 1.2. Tree diagram

A simplified graphical representation of the data model is used in Section 5 of this this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

### 1.3. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

| Prefix   | YANG module           | Reference   |
|----------|-----------------------|-------------|
| rt       | ietf-routing-types    | [RFC8294]   |
| te       | ietf-te               | [TE-Tunnel] |
| te-types | ietf-te-types         | [TE-Types]  |
| te-tel   | ietf-te-kpi-telemetry | [This I-D]  |
| vn       | ietf-vn               | [VN]        |
| vn-tel   | ietf-vn-kpi-telemetry | [This I-D]  |

Table 1: Prefixes and corresponding YANG modules

## 2. Use-Cases

[PERF] describes use-cases relevant to this draft. It introduces the dynamic creation, modification and optimization of services based on the performance monitoring. Figure 1 shows a high-level workflows for dynamic service control based on traffic monitoring.

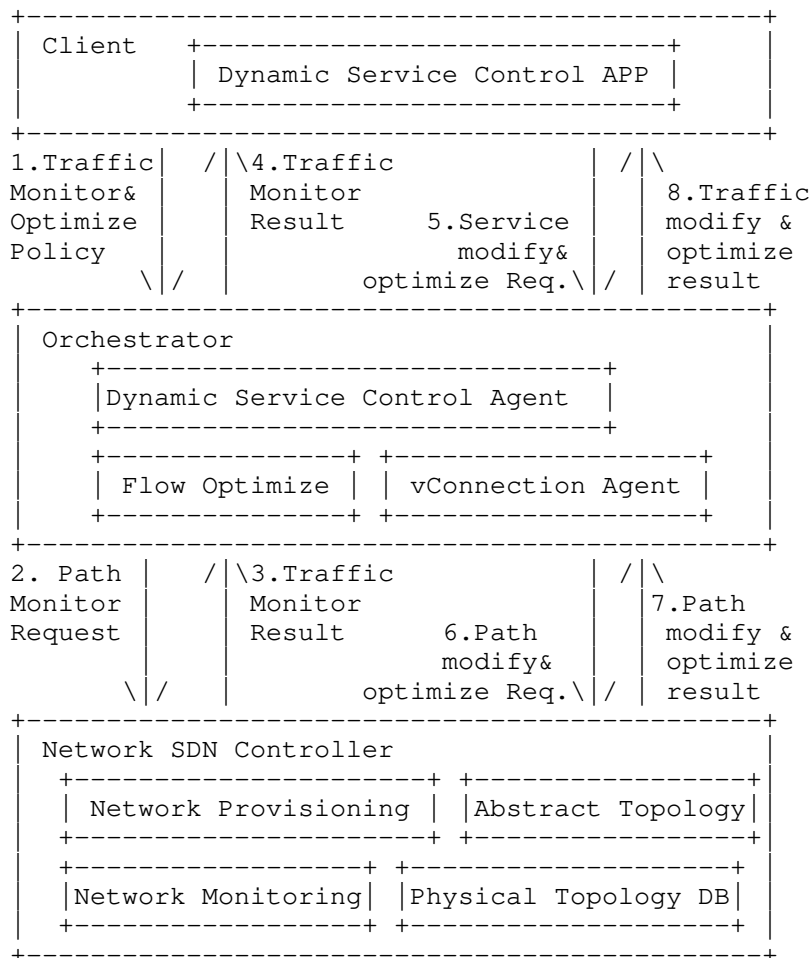


Figure 1 Workflows for dynamic service control based on traffic monitoring

Some of the key points from [PERF] are as follows:

- . Network traffic monitoring is important to facilitate automatic discovery of the imbalance of network traffic, and initiate the network optimization, thus helping the network operator or the virtual network service provider to use the network more efficiently and save the Capital Expense (CAPEX) and the Operating Expense (OPEX).

- . Customer services have various Service Level Agreement (SLA) requirements, such as service availability, latency, latency jitter, packet loss rate, Bit Error Rate (BER), etc. The transport network can satisfy service availability and BER requirements by providing different protection and restoration mechanisms. However, for other performance parameters, there are no such mechanisms. In order to provide high quality services according to customer SLA, one possible solution is to measure the SLA related performance parameters, and dynamically provision and optimize services based on the performance monitoring results.
- . Performance monitoring in a large scale network could generate a huge amount of performance information. Therefore, the appropriate way to deliver the information in the client and network interfaces should be carefully considered.

### 3. Design of the Data Models

The YANG models developed in this document describe two models:

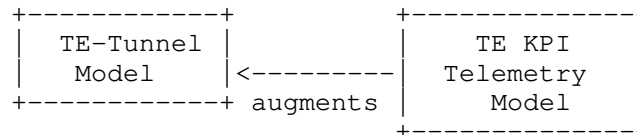
- (i) TE KPI Telemetry Model which provides the TE-Tunnel level of performance monitoring mechanism and scaling intent mechanism that allows scale in/out programming by the customer. (See Section 3.1 & 7.1 for details).
- (ii) VN KPI Telemetry Model which provides the VN level of the aggregated performance monitoring mechanism and scaling intent mechanism that allows scale in/out programming by the customer (See Section 3.2 & 7.2 for details).

#### 3.1. TE KPI Telemetry Model

This module describes performance telemetry for TE-tunnel model. The telemetry data is augmented to tunnel state. This module also allows autonomic traffic engineering scaling intent configuration mechanism on the TE-tunnel level. Various conditions can be set for auto-scaling based on the telemetry data (See Section 5 for details)

The TE KPI Telemetry Model augments the TE-Tunnel Model to enhance TE performance monitoring capability. This monitoring capability

will facilitate proactive re-optimization and reconfiguration of TEs based on the performance monitoring data collected via the TE KPI Telemetry YANG model.

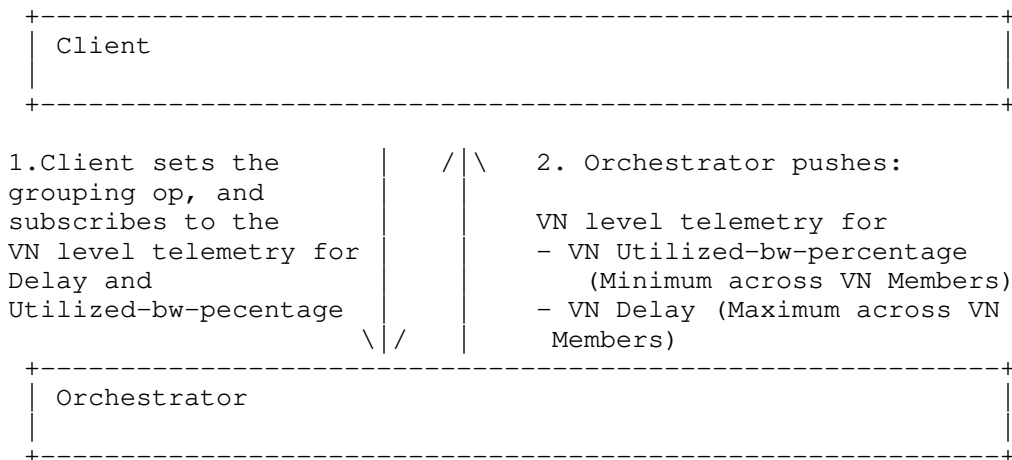


### 3.2. VN KPI Telemetry Model

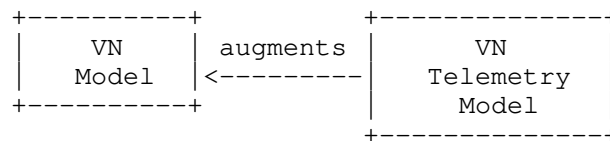
This module describes performance telemetry for VN model. The telemetry data is augmented both at the VN Level as well as individual VN member level. This module also allows autonomic traffic engineering scaling intent configuration mechanism on the VN level. Scale in/out criteria might be used for network autonomics in order the controller to react to a certain set of variations in monitored parameters (See Section 4 for illustrations).

Moreover, this module also provides mechanism to define aggregated telemetry parameters as a grouping of underlying VN level telemetry parameters. Grouping operation (such as maximum, mean) could be set at the time of configuration. For example, if maximum grouping operation is used for delay at the VN level, the VN telemetry data is reported as the maximum {delay\_vn\_member\_1, delay\_vn\_member\_2,... delay\_vn\_member\_N}. Thus, this telemetry abstraction mechanism allows the grouping of a certain common set of telemetry values under a grouping operation. This can be done at the VN-member level to suggest how the E2E telemetry be inferred from the per domain tunnel created and monitored by PNCs. One proposed example is the following:





The VN Telemetry Model augments the basic VN model to enhance VN monitoring capability. This monitoring capability will facilitate proactive re-optimization and reconfiguration of VNs based on the performance monitoring data collected via the VN Telemetry YANG model.



#### 4. Autonomic Scaling Intent Mechanism

Scaling intent configuration mechanism allows the client to configure automatic scale-in and scale-out mechanisms on both the TE-tunnel and the VN level. Various conditions can be set for auto-scaling based on the PM telemetry data.

There are a number of parameters involved in the mechanism:

- . scale-out-intent or scale-in-intent: whether to scale-out or scale-in.
- . performance-type: performance metric type (e.g., one-way-delay, one-way-delay-min, one-way-delay-max, two-way-delay, two-way-delay-min, two-way-delay-max, utilized bandwidth, etc.)

- . threshold-value: the threshold value for a certain performance-type that triggers scale-in or scale-out.
- . scaling-operation-type: in case where scaling condition can be set with one or more performance types, then scaling-operation-type (AND, OR, MIN, MAX, etc.) is applied to these selected performance types and its threshold values.
- . Threshold-time: the duration for which the criteria must hold true.
- . Cooldown-time: the duration after a scaling action has been triggered, for which there will be no further operation.

The following tree is a part of ietf-te-kpi-telemetry tree whose model is presented in full detail in Sections 6 & 7.

```

module: ietf-te-kpi-telemetry
augment /te:te/te:tunnels/te:tunnel:
 +-rw te-scaling-intent
 | +-rw scale-in-intent
 | | +-rw threshold-time? uint32
 | | +-rw cooldown-time? uint32
 | | +-rw scale-in-operation-type? scaling-criteria-operation
 | | +-rw scaling-condition* [performance-type]
 | | +-rw performance-type identityref
 | | +-rw threshold-value? string
 | | +-rw te-telemetry-tunnel-ref?
 | | -> /te:te/tunnels/tunnel/name
 | +-rw scale-out-intent
 | | +-rw threshold-time? uint32
 | | +-rw cooldown-time? uint32
 | | +-rw scale-out-operation-type? scaling-criteria-operation
 | | +-rw scaling-condition* [performance-type]
 | | +-rw performance-type identityref
 | | +-rw threshold-value? string
 | | +-rw te-telemetry-tunnel-ref?
 | | -> /te:te/tunnels/tunnel/name

```

Let say the client wants to set the scaling out operation based on two performance-types (e.g., two-way-delay and utilized-bandwidth for a te-tunnel), it can be done as follows:

- . Set Threshold-time: x (sec) (duration for which the criteria must hold true)

- . Set Cooldown-time: y (sec) (the duration after a scaling action has been triggered, for which there will be no further operation)
- . Set AND for the scale-out-operation-type

In the scaling condition's list, the following two components can be set:

List 1: Scaling Condition for Two-way-delay

- . performance type: Two-way-delay
- . threshold-value: z milli-seconds

List 2: Scaling Condition for Utilized bandwidth

- . performance type: Utilized bandwidth
- . threshold-value: w megabytes

## 5. Notification

This model does not define specific notifications. To enable notifications, the mechanism defined in [YANG-PUSH] and [Event-Notification] can be used. This mechanism currently allows the user to:

- . Subscribe to notifications on a per client basis.
- . Specify subtree filters or xpath filters so that only interested contents will be sent.
- . Specify either periodic or on-demand notifications.

### 5.1. YANG Push Subscription Examples

[YANG-PUSH] allows subscriber applications to request a continuous, customized stream of updates from a YANG datastore.

Below example shows the way for a client to subscribe to the telemetry information for a particular tunnel (Tunnel1). The telemetry parameter that the client is interested in is one-way-delay.

```

<netconf:rpc netconf:message-id="101"
 xmlns:netconf="urn:ietf:params:xml:ns:netconf:base:1.0">
 <establish-subscription
 xmlns="urn:ietf:params:xml:ns:yang:ietf-yang-push:1.0">
 <filter netconf:type="subtree">
 <te xmlns="urn:ietf:params:xml:ns:yang:ietf-te">
 <tunnels>
 <tunnel>
 <name>Tunnel1</name>
 <identifier/>
 <state>
 <te-telemetry xmlns="urn:ietf:params:xml:ns:yang:
 ietf-te-kpi-telemetry">
 <one-way-delay/>
 </te-telemetry>
 </state>
 </tunnel>
 </tunnels>
 </te>
 </filter>
 <period>500</period>
 <encoding>encode-xml</encoding>
 </establish-subscription>
</netconf:rpc>

```

This example shows the way for a client to subscribe to the telemetry information for all VNs. The telemetry parameter that the client is interested in is one-way-delay and one-way-utilized-bandwidth.

```

<netconf:rpc netconf:message-id="101"
 xmlns:netconf="urn:ietf:params:xml:ns:netconf:base:1.0">
 <establish-subscription
 xmlns="urn:ietf:params:xml:ns:yang:ietf-yang-push:1.0">
 <filter netconf:type="subtree">
 <vn-state xmlns="urn:ietf:params:xml:ns:yang:ietf-vn">
 <vn>
 <vn-list>
 <vn-id/>
 <vn-name/>
 <vn-telemetry xmlns="urn:ietf:params:xml:ns:yang:
 ietf-vn-kpi-telemetry">
 <one-way-delay/>
 <one-way-utilized-bandwidth/>
 </vn-telemetry >
 </vn-list>
 </vn>
 </vn-state>
 </filter>
 <period>500</period>
 </establish-subscription>
</netconf:rpc>

```

## 6. YANG Data Tree

```

module: ietf-te-kpi-telemetry
augment /te:te/te:tunnels/te:tunnel:
 +--rw te-scaling-intent
 |
 | +--rw scale-in-intent
 | | +--rw threshold-time? uint32
 | | +--rw cooldown-time? uint32
 | | +--rw scale-in-operation-type? scaling-criteria-operation
 | | +--rw scaling-condition* [performance-type]
 | | | +--rw performance-type identityref
 | | | +--rw threshold-value? string
 | | | +--rw te-telemetry-tunnel-ref?
 | | | -> /te:te/tunnels/tunnel/name
 | | +--rw scale-out-intent
 | | | +--rw threshold-time? uint32
 | | | +--rw cooldown-time? uint32
 | | | +--rw scale-out-operation-type? scaling-criteria-operation
 | | | +--rw scaling-condition* [performance-type]
 | | | | +--rw performance-type identityref
 | | | | +--rw threshold-value? string
 | | | | +--rw te-telemetry-tunnel-ref?
 | | | -> /te:te/tunnels/tunnel/name
 | +--ro te-telemetry
 | | +--ro id? string
 | | +--ro performance-metrics-one-way
 | | | +--ro one-way-delay? uint32
 | | | +--ro one-way-delay-normality?
 | | | | te-types:performance-metrics-normality
 | | | +--ro one-way-residual-bandwidth?
 | | | | rt-types:bandwidth-ieee-float32
 | | | +--ro one-way-residual-bandwidth-normality?
 | | | | te-types:performance-metrics-normality
 | | | +--ro one-way-available-bandwidth?
 | | | | rt-types:bandwidth-ieee-float32
 | | | +--ro one-way-available-bandwidth-normality?
 | | | | te-types:performance-metrics-normality
 | | | +--ro one-way-utilized-bandwidth?
 | | | | rt-types:bandwidth-ieee-float32
 | | | +--ro one-way-utilized-bandwidth-normality?
 | | | te-types:performance-metrics-normality
 | | +--ro performance-metrics-two-way
 | | | +--ro two-way-delay? uint32
 | | | +--ro two-way-delay-normality?
 | | | te-types:performance-metrics-normality
 | | +--ro te-ref?
 | -> /te:te/tunnels/tunnel/name

module: ietf-vn-kpi-telemetry
augment /vn:vn/vn:vn-list:

```

```

+--rw vn-scaling-intent
| +--rw scale-in-intent
| | +--rw threshold-time? uint32
| | +--rw cooldown-time? uint32
| | +--rw scale-in-operation-type? scaling-criteria-operation
| | +--rw scaling-condition* [performance-type]
| | | +--rw performance-type identityref
| | | +--rw threshold-value? string
| | | +--rw te-telemetry-tunnel-ref?
| | | | -> /te:te/tunnels/tunnel/name
| | +--rw scale-out-intent
| | | +--rw threshold-time? uint32
| | | +--rw cooldown-time? uint32
| | | +--rw scale-out-operation-type? scaling-criteria-operation
| | | +--rw scaling-condition* [performance-type]
| | | | +--rw performance-type identityref
| | | | +--rw threshold-value? string
| | | | +--rw te-telemetry-tunnel-ref?
| | | | | -> /te:te/tunnels/tunnel/name
| +--ro vn-telemetry
| | +--ro performance-metrics-one-way
| | | +--ro one-way-delay? uint32
| | | +--ro one-way-delay-normality?
| | | | te-types:performance-metrics-normality
| | | +--ro one-way-residual-bandwidth?
| | | | rt-types:bandwidth-ieee-float32
| | | +--ro one-way-residual-bandwidth-normality?
| | | | te-types:performance-metrics-normality
| | | +--ro one-way-available-bandwidth?
| | | | rt-types:bandwidth-ieee-float32
| | | +--ro one-way-available-bandwidth-normality?
| | | | te-types:performance-metrics-normality
| | | +--ro one-way-utilized-bandwidth?
| | | | rt-types:bandwidth-ieee-float32
| | | +--ro one-way-utilized-bandwidth-normality?
| | | | te-types:performance-metrics-normality
| | +--ro performance-metrics-two-way
| | | +--ro two-way-delay? uint32
| | | +--ro two-way-delay-normality?
| | | | te-types:performance-metrics-normality
| | +--ro grouping-operation? grouping-operation
augment /vn:vn/vn:vn-list/vn:vn-member-list:
+--ro vn-member-telemetry
| +--ro performance-metrics-one-way
| | +--ro one-way-delay? uint32
| | +--ro one-way-delay-normality?
| | | te-types:performance-metrics-normality
| | +--ro one-way-residual-bandwidth?
| | | rt-types:bandwidth-ieee-float32
| | +--ro one-way-residual-bandwidth-normality?
| | | te-types:performance-metrics-normality
| | +--ro one-way-available-bandwidth?
| | | rt-types:bandwidth-ieee-float32
| | +--ro one-way-available-bandwidth-normality?
| | | te-types:performance-metrics-normality

```

```

 | +--ro one-way-utilized-bandwidth?
 | | rt-types:bandwidth-ieee-float32
 | +--ro one-way-utilized-bandwidth-normality?
 | te-types:performance-metrics-normality
+--ro performance-metrics-two-way
 | +--ro two-way-delay? uint32
 | +--ro two-way-delay-normality?
 | te-types:performance-metrics-normality
+--ro te-grouped-params*
 | -> /te:te/tunnels/tunnel/te-kpi:te-telemetry/id
+--ro grouping-operation? grouping-operation

```

## 7. Yang Data Model

### 7.1. ietf-te-kpi-telemetry model

The YANG code is as follows:

<CODE BEGINS> file "ietf-te-kpi-telemetry@2019-04-18.yang"

```

module ietf-te-kpi-telemetry {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te-kpi-telemetry";
 prefix te-tel;

 import ietf-te {
 prefix te;
 reference
 "RFC YYYY: A YANG Data Model for Traffic Engineering
 Tunnels and Interfaces";
 }

 /* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-ietf-teas-yang-te
 becomes an RFC.*/

 import ietf-te-types {
 prefix te-types;
 reference
 "RFC YYYY: Traffic Engineering Common YANG Types";
 }

 /* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-ietf-teas-yang-te-types
 becomes an RFC.*/

```

```
organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";
contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Editor: Dhruv Dhody <dhruv.ietf@gmail.com>
 Editor: Ricard Vilalta <ricard.vilalta@cttc.es>
 Editor: Satish Karunanithi <satish.karunanithi@gmail.com>";
description
 "This module describes YANG data model for performance
 monitoring telemetry for te tunnels.

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 (http://trustee.ietf.org/license-info).

 This version of this YANG module is part of RFC XXXX; see
 the RFC itself for full legal notices.";

/* Note: The RFC Editor will replace XXXX with the number
 assigned to the RFC once draft-lee-teas-pm-telemetry-
 autonomics becomes an RFC.*/

revision 2019-04-18 {
 description
 "Initial revision. This YANG file defines
 a YANG model for TE telemetry.";
 reference "Derived from earlier versions of base YANG files";
}

identity telemetry-param-type {
 description
 "Base identity for telemetry param types";
}

identity one-way-delay {
 base telemetry-param-type;
 description
 "To specify average Delay in one (forward)
 direction";
```



```
reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC8570: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

identity two-way-delay {
 base telemetry-param-type;
 description
 "To specify average Delay in both (forward and reverse)
 directions";
 reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC8570: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

identity one-way-delay-variation {
 base telemetry-param-type;
 description
 "To specify average Delay Variation in one (forward) direction";
 reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC8570: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

identity two-way-delay-variation {
 base telemetry-param-type;
 description
 "To specify average Delay Variation in both (forward and reverse)
 directions";
 reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC8570: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

identity utilized-bandwidth {
```

```
 base telemetry-param-type;
 description
 "To specify utilized bandwidth over the specified source
 and destination.";
 reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC8570: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

identity utilized-percentage {
 base telemetry-param-type;
 description
 "To specify utilization percentage of the entity
 (e.g., tunnel, link, etc.)";
}

typedef scaling-criteria-operation {
 type enumeration {
 enum AND {
 description
 "AND operation";
 }
 enum OR {
 description
 "OR operation";
 }
 }
 description
 "Operations to analyze list of scaling criterias";
}

grouping scaling-duration {
 description
 "Base scaling criteria durations";
 leaf threshold-time {
 type uint32;
 units "seconds";
 description
 "The duration for which the criteria must hold true";
 }
 leaf cooldown-time {
 type uint32;
 units "seconds";
 description
```

```
 "The duration after a scaling-in/scaling-out action has been
 triggered, for which there will be no further operation";
 }
}

grouping scaling-criteria {
 description
 "Grouping for scaling criteria";
 leaf performance-type {
 type identityref {
 base telemetry-param-type;
 }
 description
 "Reference to the tunnel level telemetry type";
 }
 leaf threshold-value {
 type string;
 description
 "Scaling threshold for the telemetry parameter type";
 }
 leaf te-telemetry-tunnel-ref {
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/te:name";
 }
 description
 "Reference to tunnel";
 }
}

grouping scaling-in-intent {
 description
 "Basic scaling in intent";
 uses scaling-duration;
 leaf scale-in-operation-type {
 type scaling-criteria-operation;
 default "AND";
 description
 "Operation to be applied to check between
 scaling criterias to check if the scale in
 threshold condition has been met.
 Defaults to AND";
 }
 list scaling-condition {
 key "performance-type";
 description
 "Scaling conditions";
 uses scaling-criteria;
 }
}
```

```
 }
 }

 grouping scaling-out-intent {
 description
 "Basic scaling out intent";
 uses scaling-duration;
 leaf scale-out-operation-type {
 type scaling-criteria-operation;
 default "OR";
 description
 "Operation to be applied to check between
 scaling criterias to check if the scale out
 threshold condition has been met.
 Defaults to OR";
 }
 list scaling-condition {
 key "performance-type";
 description
 "Scaling conditions";
 uses scaling-criteria;
 }
 }

 augment "/te:te/te:tunnels/te:tunnel" {
 description
 "Augmentation parameters for config scaling-criteria
 TE tunnel topologies. Scale in/out criteria might be used
 for network autonomics in order the controller
 to react to a certain set of monitored params.";
 container te-scaling-intent {
 description
 "scaling intent";
 container scale-in-intent {
 description
 "scale-in";
 uses scaling-in-intent;
 }
 container scale-out-intent {
 description
 "scale-out";
 uses scaling-out-intent;
 }
 }
 container te-telemetry {
 config false;
 description
```

```

 "telemetry params";
 leaf id {
 type string;
 description
 "Id of telemetry param";
 }
 uses te-types:performance-metrics-attributes;
 leaf te-ref {
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/te:name";
 }
 description
 "Reference to measured te tunnel";
 }
}
}
}
<CODE ENDS>

```

## 7.2. ietf-vn-kpi-telemetry model

The YANG code is as follows:

```

<CODE BEGINS> file "ietf-vn-kpi-telemetry@2019-04-18.yang"

module ietf-vn-kpi-telemetry {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-vn-kpi-telemetry";
 prefix vn-tel;

 import ietf-vn {
 prefix vn;
 reference
 "RFC YYYY: A YANG Data Model for VN Operation";
 }

 /* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-ietf-teas-actn-vn-yang
 becomes an RFC.*/

 import ietf-te {
 prefix te;
 reference
 "RFC YYYY: A YANG Data Model for Traffic Engineering

```

```
 Tunnels and Interfaces";
}

/* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-ietf-teas-yang-te
 becomes an RFC.*/

import ietf-te-types {
 prefix te-types;
 reference
 "RFC YYYY: Traffic Engineering Common YANG Types";
}

/* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-ietf-teas-yang-te-types
 becomes an RFC.*/

import ietf-te-kpi-telemetry {
 prefix te-kpi;
 reference
 "RFC YYYY: YANG models for VN & TE Performance Monitoring
 Telemetry and Scaling Intent Autonomics";
}

/* Note: The RFC Editor will replace YYYY with the number
 assigned to the RFC once draft-lee-teas-actn-pm-telemetry
 -autonomics becomes an RFC.*/

organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";
contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Editor: Dhruv Dhody <dhruv.ietf@gmail.com>
 Editor: Ricard Vilalta <ricard.vilalta@cttc.es>
 Editor: Satish Karunanithi <satish.karunanithi@gmail.com>";

description
 "This module describes YANG data models for performance
 monitoring telemetry for vn.

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```

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This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.";

/\* Note: The RFC Editor will replace XXXX with the number assigned to the RFC once draft-lee-teas-pm-telemetry-autonomics becomes an RFC.\*/

```
revision 2019-04-18 {
 description
 "Initial revision. This YANG file defines
 the VN telemetry.";
 reference "Derived from earlier versions of base YANG files";
}

typedef grouping-operation {
 type enumeration {
 enum MINIMUM {
 description
 "Select the minimum param";
 }
 enum MAXIMUM {
 description
 "Select the maximum param";
 }
 enum MEAN {
 description
 "Select the MEAN of the params";
 }
 enum STD_DEV {
 description
 "Select the standard deviation of the
 monitored params";
 }
 enum AND {
 description
 "Select the AND of the params";
 }
 enum OR {
 description
 "Select the OR of the params";
 }
 }
 description
```

```
 "Operations to analyze list of monitored params";
}

grouping vn-telemetry-param {
 description
 "augment of te-kpi:telemetry-param for VN specific params";
 leaf-list te-grouped-params {
 type leafref {
 path "/te:te/te:tunnels/te:tunnel/te-kpi:te-telemetry/te-kpi:id";
 }
 description
 "Allows the definition of a vn-telemetry param
 as a grouping of underlying TE params";
 }
 leaf grouping-operation {
 type grouping-operation;
 description
 "describes the operation to apply to
 te-grouped-params";
 }
}

augment "/vn:vn/vn:vn-list" {
 description
 "Augmentation parameters for state TE VN topologies.";
 container vn-scaling-intent {
 description
 "scaling intent";
 container scale-in-intent {
 description
 "VN scale-in";
 uses te-kpi:scaling-in-intent;
 }
 container scale-out-intent {
 description
 "VN scale-out";
 uses te-kpi:scaling-out-intent;
 }
 }
 container vn-telemetry {
 config false;
 description
 "VN telemetry params";
 uses te-types:performance-metrics-attributes;
 leaf grouping-operation {
 type grouping-operation;
 description
```



```
 "describes the operation to apply to the VN-members";
 }
}
}
augment "/vn:vn/vn:vn-list/vn:vn-member-list" {
 description
 "Augmentation parameters for state TE vn member topologies.";
 container vn-member-telemetry {
 config false;
 description
 "VN member telemetry params";
 uses te-types:performance-metrics-attributes;
 uses vn-telemetry-param;
 }
}
}
<CODE ENDS>
```

## 8. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF users to a preconfigured subset of all available NETCONF protocol operations and content. The NETCONF Protocol over Secure Shell (SSH) [RFC6242] describes a method for invoking and running NETCONF within a Secure Shell (SSH) session as an SSH subsystem. The Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

A number of configuration data nodes defined in this document are writable/deletable (i.e., "config true"). These data nodes may be considered sensitive or vulnerable in some network environments.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or

vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

```
/te:te/te:tunnels/te:tunnel/te-scaling-intent/scale-in-intent
/te:te/te:tunnels/te:tunnel/te-scaling-intent/scale-out-intent

/vn:vn/vn:vn-list/vn-scaling-intent/scale-in-intent
/vn:vn/vn:vn-list/vn-scaling-intent/scale-out-intent
```

## 9. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```

URI: urn:ietf:params:xml:ns:yang:ietf-te-kpi-telemetry
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-vn-kpi-telemetry
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

This document registers the following YANG modules in the YANG Module.

Names registry [RFC7950]:

```

name: ietf-te-kpi-telemetry
namespace: urn:ietf:params:xml:ns:yang:ietf-te-kpi-telemetry
prefix: te-tel
reference: RFC XXXX (TDB)

```

```


name: ietf-vn-kpi-telemetry
namespace: urn:ietf:params:xml:ns:yang:ietf-vn-kpi-telemetry
prefix: vn-tel
reference: RFC XXXX (TDB)

```

## 10. Acknowledgements

We thank Rakesh Gandhi, Tarek Saad and Igor Bryskin for useful discussions and their suggestions for this work.

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## A Yang Data Model for ACTN VN Operation

draft-lee-teas-actn-vn-yang-13

### Abstract

This document provides a YANG data model for the Abstraction and Control of Traffic Engineered (TE) networks (ACTN) Virtual Network Service (VNS) operation.

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Lee, et al.

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## 1. Introduction

This document provides a YANG data model for the Abstraction and Control of Traffic Engineered (TE) networks (ACTN) Virtual Network Service (VNS) operation that is going to be implemented for the Customer Network Controller (CNC)- Multi-Domain Service Coordinator (MSDC) interface (CMI).

The YANG model on the CMI is also known as customer service model in [Service-YANG]. The YANG model discussed in this document is used to operate customer-driven VNs during the VN computation, VN instantiation and its life-cycle management and operations.

The YANG model discussed in this document basically provides the following:

- o Characteristics of Access Points (APs) that describe customer's end point characteristics;
- o Characteristics of Virtual Network Access Points (VNAP) that describe How an AP is partitioned for multiple VNs sharing the AP and its reference to a Link Termination Point (LTP) of the Provider Edge (PE) Node;
- o Characteristics of Virtual Networks (VNs) that describe the customer's VNs in terms of VN Members comprising a VN, multi-source and/or multi-destination characteristics of VN Member, the VN's reference to TE-topology's Abstract Node;

The actual VN instantiation is performed with Connectivity Matrices sub-module of TE-Topology Model [TE-Topo] which interacts with the VN YANG module presented in this draft. Once TE-topology Model is used in triggering VN instantiation over the networks, TE-tunnel [TE-tunnel] Model will inevitably interact with TE-Topology model for setting up actual tunnels and LSPs under the tunnels.

The ACTN VN operational state is included in the same tree as the configuration consistent with Network Management Datastore Architecture (NMDA) [NMDA]. The origin of the data is indicated as per the origin metadata annotation.

### 1.1. Terminology

Refer to [ACTN-Frame] and [RFC7926] for the key terms used in this document.

### 2. ACTN CMI context

The model presented in this document has the following ACTN context.

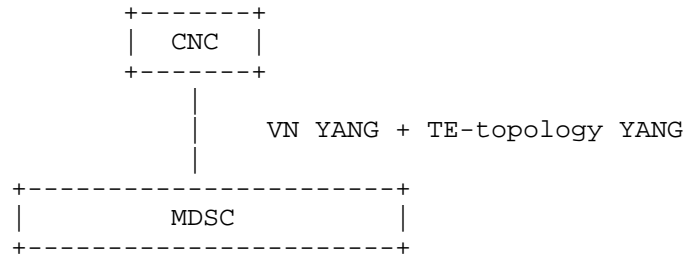


Figure 1. ACTN CMI

Both ACTN VN YANG and TE-topology models are used over the CMI to establish a VN over TE networks.

#### 2.1. Type 1 VN

As defined in [ACTN-FW], a Virtual Network is a customer view of the TE network. To recapitulate VN types from [ACTN-FW], Type 1 VN is defined as follows:

The VN can be seen as a set of edge-to-edge links (a Type 1 VN). Each link is referred to as a VN member and is formed as an end-to-end tunnel across the underlying networks. Such tunnels may be constructed by recursive slicing or abstraction of paths in the underlying networks and can encompass edge points of the customer's network, access links, intra-domain paths, and inter-domain links.

If we were to create a VN where we have four VN-members as follows:

|             |       |
|-------------|-------|
| VN-Member 1 | L1-L4 |
| VN-Member 2 | L1-L7 |
| VN-Member 3 | L2-L4 |
| VN-Member 4 | L3-L8 |

Where L1, L2, L3, L4, L7 and L8 correspond to a Customer End-Point, respectively.

This VN can be modeled as one abstract node representation as follows in Figure 2:

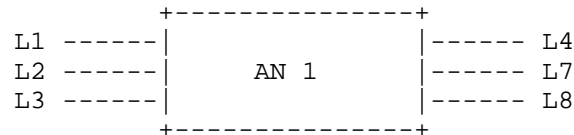


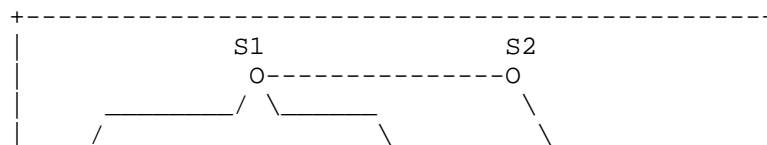
Figure 2. Abstract Node (One node topology)

Modeling a VN as one abstract node is the easiest way for customers to express their end-to-end connectivity; however, customers are not limited to express their VN only with one abstract node. In some cases, more than one abstract nodes can be employed to express their VN.

## 2.2. Type 2 VN

For some VN members of a VN, the customers are allowed to configure the actual path (i.e., detailed virtual nodes and virtual links) over the VN/abstract topology agreed mutually between CNC and MDSC prior to or a topology created by the MDSC as part of VN instantiation. Type 2 VN is always built on top of a Type 1 VN.

If a Type 2 VN is desired for some or all of VN members of a type 1 VN (see the example in Section 2.1), the TE-topology model can provide the following abstract topology (that consists of virtual nodes and virtual links) which is built on top of the Type 1 VN.



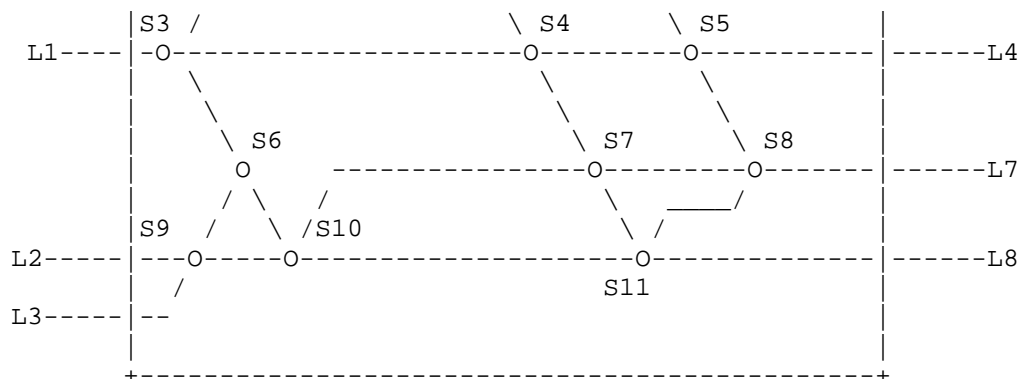


Figure 3. Type 2 topology

As you see from Figure 3, the Type 1 abstract node is depicted as a Type 1 abstract topology comprising of detailed virtual nodes and virtual links.

As an example, if VN-member 1 (L1-L4) is chosen to configure its own path over Type 2 topology, it can select, say, a path that consists of the ERO {S3,S4,S5} based on the topology and its service requirement. This capability is enacted via TE-topology configuration by the customer.

### 3. High-Level Control Flows with Examples

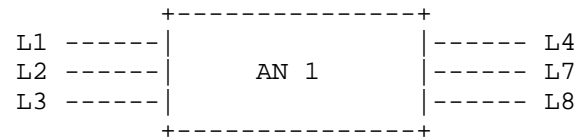
### 3.1. Type 1 VN Illustration

If we were to create a VN where we have four VN-members as follows:

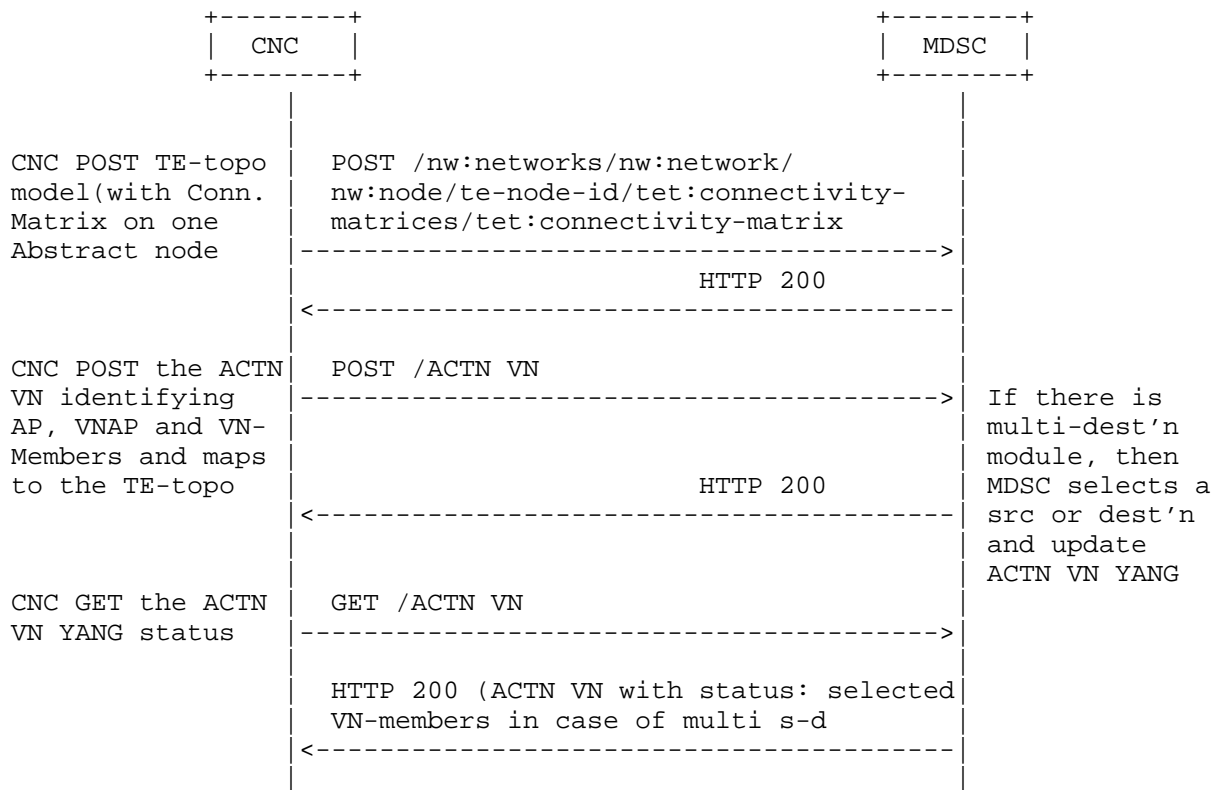
|             |       |
|-------------|-------|
| VN-Member 1 | L1-L4 |
| VN-Member 2 | L1-L7 |
| VN-Member 3 | L2-L4 |
| VN-Member 4 | L3-L8 |

Where L1, L2, L3, L4, L7 and L8 correspond to Customer End-Point, respectively.

This VN can be modeled as one abstract node representation as follows:



If this VN is Type 1, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using ACTN VN and TE-Topology Model.

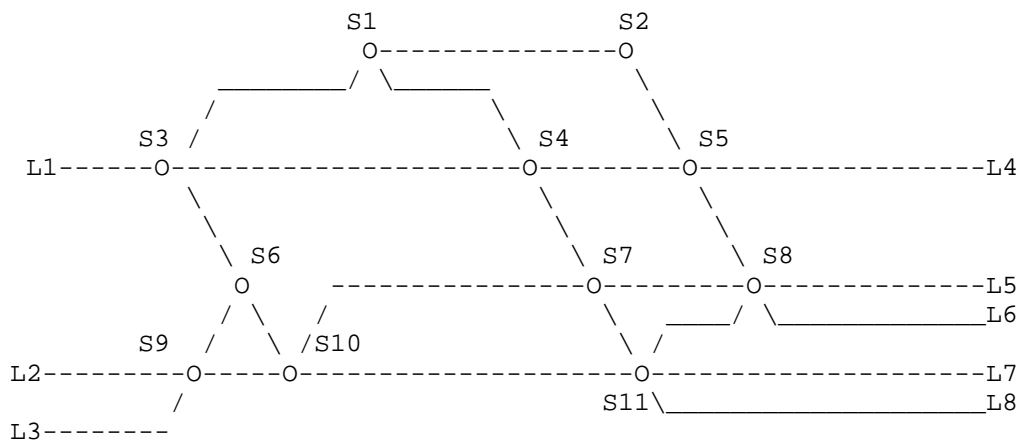


### 3.2. Type 2 VN Illustration

For some VN members, the customer may want to "configure" explicit routes over the path that connects its two end-points. Let us consider the following example.

|             |                       |
|-------------|-----------------------|
| VN-Member 1 | L1-L4                 |
| VN-Member 2 | L1-L7 (via S4 and S7) |
| VN-Member 3 | L2-L4                 |
| VN-Member 4 | L3-L8 (via S10)       |

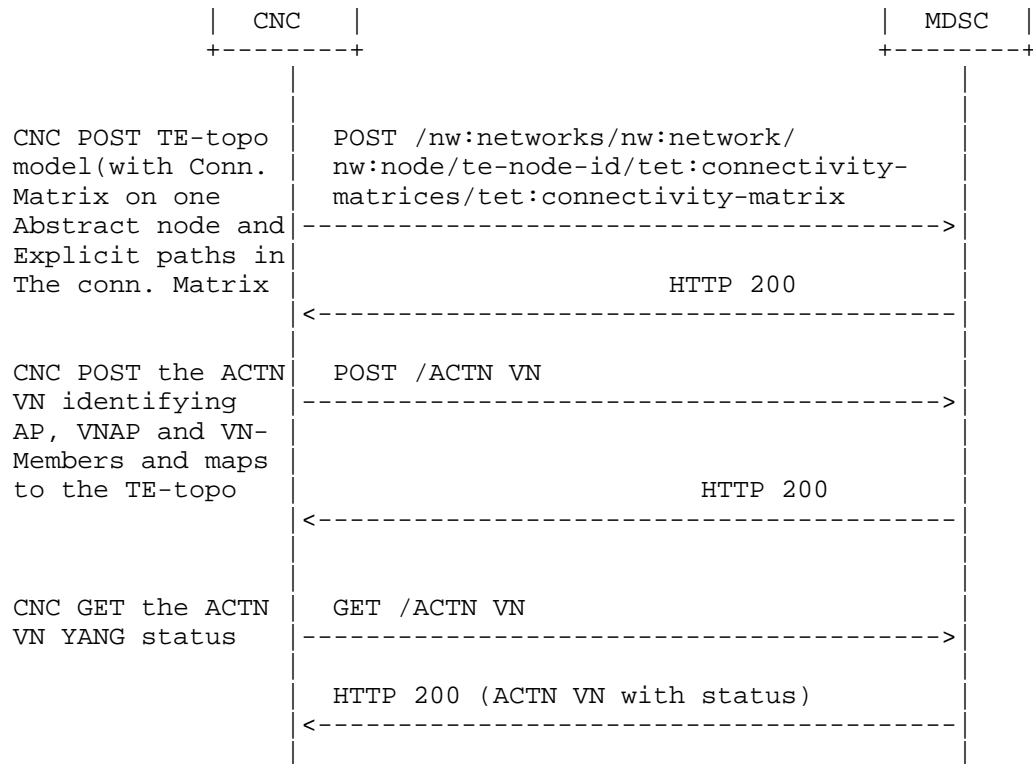
Where the following topology is the underlay for Abstraction Node 1 (AN1).



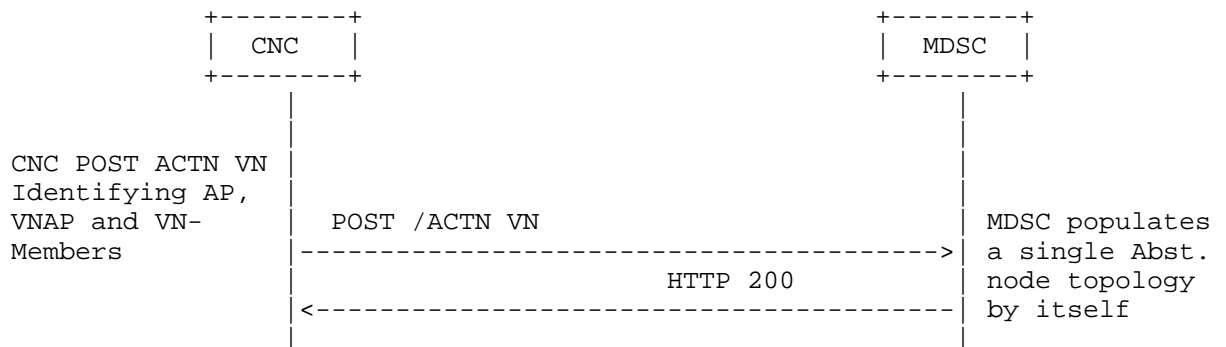
If CNC creates the single abstract topology, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using ACTN VN and TE-Topology Model.

+-----+

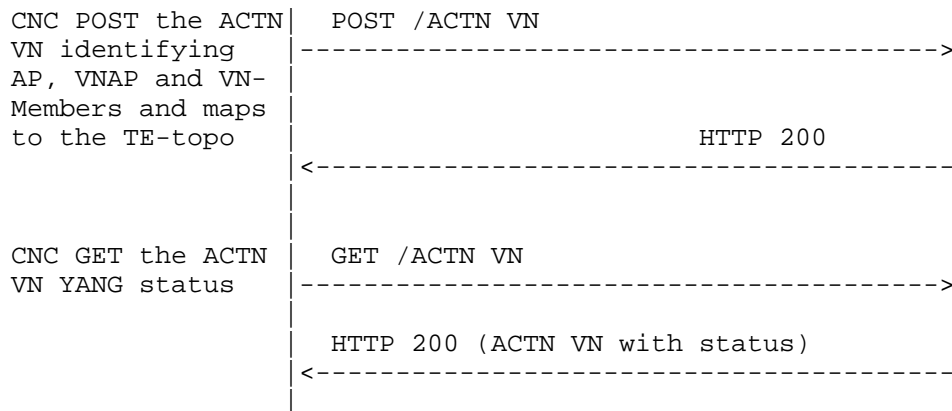
+-----+



On the other hand, if MDSC create single node topology based ACTN VN YANG posted by the CNC, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using ACTN VN and TE-Topology Model.







#### 4. Justification of the ACTN VN Model on the CMI.

##### 4.1. Customer view of VN

The VN-Yang model allows to define a customer view, and allows the customer to communicate using the VN constructs as described in the [ACTN-INFO]. It also allows to group the set of edge-to-edge links (i.e., VN members) under a common umbrella of VN. This allows the customer to instantiate and view the VN as one entity, making it easier for some customers to work on VN without worrying about the details of the provider based YANG models.

This is similar to the benefits of having a separate YANG model for the customer services as described in [SERVICE-YANG], which states that service models do not make any assumption of how a service is actually engineered and delivered for a customer.

##### 4.2. Innovative Services

###### 4.2.1. VN Compute

ACTN VN supports VN compute (pre-instantiation mode) to view the full VN as a single entity before instantiation. Achieving this via path computation or "compute only" tunnel setup does not provide the same functionality.

#### 4.2.2. Multi-sources and Multi-destinations

In creating a virtual network, the list of sources or destinations or both may not be pre-determined by the customer. For instance, for a given source, there may be a list of multiple-destinations to which the optimal destination may be chosen depending on the network resource situations. Likewise, for a given destination, there may also be multiple-sources from which the optimal source may be chosen. In some cases, there may be a pool of multiple sources and destinations from which the optimal source-destination may be chosen. The following YANG module is shown for describing source container and destination container. The following YANG tree shows how to model multi-sources and multi-destinations.

```

+--rw actn
 . . .
 +--rw vn
 +--rw vn-list* [vn-id]
 +--rw vn-id uint32
 +--rw vn-name? string
 +--rw vn-topology-id? te-types:te-topology-id
 +--rw abstract-node? -> /nw:networks/network/node/tet:te-node-id
 +--rw vn-member-list* [vn-member-id]
 | +--rw vn-member-id uint32
 | +--rw src
 | | +--rw src? -> /actn/ap/access-point-list/access-po
int-id | | +--rw src-vn-ap-id? -> /actn/ap/access-point-list/vn-ap/vn-
ap-id | | +--rw multi-src? boolean {multi-src-dest}?
 | | +--rw dest
 | | +--rw dest? -> /actn/ap/access-point-list/access-p
oint- | | +--rw dest-vn-ap-id? -> /actn/ap/access-point-list/vn-ap/vn
id | | +--rw multi-dest? boolean {multi-src-dest}?
 | | +--rw connetivity-matrix-id? -> /nw:networks/network/node/tet:
te/te- | +--ro oper-status? identityref
node-attributes/connectivity-matrices/connectivity-matrix/id
 | +--ro if-selected? boolean {multi-src-dest}?
 +--rw admin-status? identityref
 +--ro oper-status? identityref

```

#### 4.2.3. Others

The VN Yang model can be easily augmented to support the mapping of VN to the Services such as L3SM and L2SM as described in [TE-MAP].

The VN Yang model can be extended to support telemetry, performance monitoring and network autonomies as described in [ACTN-PM].

#### 4.3. Summary

This section summarizes the innovative service features of the ACTN VN Yang.

- o Maintenance of AP and VNAP along with VN.
- o VN construct to group of edge-to-edge links
- o VN Compute (pre-instantiate)
- o Multi-Source / Multi-Destination
- o Ability to support various VN and VNS Types
  - \* VN Type 1: Customer configures the VN as a set of VN Members.  
No other details need to be set by customer, making for a simplified operations for the customer.
  - \* VN Type 2: Along with VN Members, the customer could also provide an abstract topology, this topology is provided by the Abstract TE Topology Yang Model.

#### 5. ACTN VN YANG Model (Tree Structure)

```
module: ietf-actn-vn
 +--rw actn
```

```

 +--rw ap
 | +--rw access-point-list* [access-point-id]
 | | +--rw access-point-id uint32
 | | +--rw access-point-name? string
 | | +--rw max-bandwidth? te-types:te-bandwidth
 | | +--rw avl-bandwidth? te-types:te-bandwidth
 | | +--rw vn-ap* [vn-ap-id]
 | | | +--rw vn-ap-id uint32
 | | | +--rw vn? -> /actn/vn/vn-list/vn-id
 | | | +--rw abstract-node? ->
 | | +--rw ltp? te-types:te-tp-id
 | +--rw vn
 | | +--rw vn-list* [vn-id]
 | | | +--rw vn-id uint32
 | | | +--rw vn-name? string
 | | | +--rw vn-topology-id? te-types:te-topology-id
 | | | +--rw abstract-node? ->
 | | +--rw vn-member-list* [vn-member-id]
 | | | +--rw vn-member-id uint32
 | | | +--rw src
 | | | | +--rw src? -> /actn/ap/access-point-
 | | | | | +--rw src-vn-ap-id? -> /actn/ap/access-point-
 | | | | | | +--rw multi-src? boolean {multi-src-dest}?
 | | | | | | +--rw dest
 | | | | | | | +--rw dest? -> /actn/ap/access-point-
 | | | | | | | | +--rw dest-vn-ap-id? -> /actn/ap/access-point-
 | | | | | | | | | +--rw multi-dest? boolean {multi-src-dest}?
 | | | | | | | | | +--rw connetivity-matrix-id? ->
 | | | | | | | | | | +--ro oper-status? identityref
 | | | | | | | | | | +--ro if-selected? boolean {multi-src-dest}?
 | | | | | | | | | | +--ro admin-status? identityref
 | | | | | | | | | | +--ro oper-status? identityref
 | | | | | | | | | | +--rw vn-level-diversity? vn-disjointness
 | | +--rw vn-level-diversity? vn-disjointness
 | +--rw vn-level-diversity? vn-disjointness
 +--rw vn-level-diversity? vn-disjointness

```

```

rpcs:
 +---x vn-compute
 +---w input
 | +---w abstract-node? ->
/nw:networks/network/node/tet:te-node-id
 | +---w vn-member-list* [vn-member-id]
 | | +---w vn-member-id uint32
 | | +---w src
 | | | +---w src? -> /actn/ap/access-point-
list/access-point-id
 | | | +---w src-vn-ap-id? -> /actn/ap/access-point-
list/vn-ap/vn-ap-id
 | | | +---w multi-src? boolean {multi-src-dest}?
 | | | +---w dest
 | | | +---w dest? -> /actn/ap/access-point-
list/access-point-id
 | | | +---w dest-vn-ap-id? -> /actn/ap/access-point-
list/vn-ap/vn-ap-id
 | | | +---w multi-dest? boolean {multi-src-dest}?
 | | | +---w connetivity-matrix-id? ->
/nw:networks/network/node/tet:te/te-node-attributes/connectivity-
matrices/connectivity-matrix/id
 | +---w vn-level-diversity? vn-disjointness
 +--ro output
 +--ro vn-member-list* [vn-member-id]
 +--ro vn-member-id uint32
 +--ro src
 | +--ro src? -> /actn/ap/access-point-
list/access-point-id
 | +--ro src-vn-ap-id? -> /actn/ap/access-point-
list/vn-ap/vn-ap-id
 | +--ro multi-src? boolean {multi-src-dest}?
 +--ro dest
 | +--ro dest? -> /actn/ap/access-point-
list/access-point-id
 | +--ro dest-vn-ap-id? -> /actn/ap/access-point-
list/vn-ap/vn-ap-id
 | +--ro multi-dest? boolean {multi-src-dest}?

```

```

 +--ro connetivity-matrix-id? ->
/nw:networks/network/node/tet:te/te-node-attributes/connectivity-
matrices/connectivity-matrix/id
 +--ro if-selected? boolean {multi-src-
dest}?
 +--ro compute-status? identityref

```

## 6. ACTN-VN YANG Code

The YANG code is as follows:

```

<CODE BEGINS> file "ietf-actn-vn@2018-02-27.yang"

module ietf-actn-vn {
 namespace "urn:ietf:params:xml:ns:yang:ietf-actn-vn";
 prefix "vn";

 /* Import network */
 import ietf-network {
 prefix "nw";
 }

 /* Import TE generic types */
 import ietf-te-types {
 prefix "te-types";
 }

 /* Import Abstract TE Topology */
 import ietf-te-topology {
 prefix "tet";
 }

 organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";
 contact
 "Editor: Young Lee <leeyoung@huawei.com>
 : Dhruv Dhody <dhruv.ietf@gmail.com>";
 description
 "This module contains a YANG module for the ACTN VN. It
 describes a VN operation module that takes place in the
 context of the CNC-MDSC Interface (CMI) of the ACTN
 architecture where the CNC is the actor of a VN

```

```
 instantiation/modification /deletion.";
revision 2018-02-27 {
 description
 "initial version.";
 reference
 "TBD";
}
/*
 * Features
 */
feature multi-src-dest {
 description
 "Support for selection of one src or destination
 among multiple.";
}

/*identity path-metric-delay {
 base te-types:path-metric-type;
 description
 "delay path metric";
}
identity path-metric-delay-variation {
 base te-types:path-metric-type;
 description
 "delay-variation path metric";
}
identity path-metric-loss {
 base te-types:path-metric-type;
 description
 "loss path metric";
}*/

identity vn-state-type {
 description
 "Base identity for VN state";
}
identity vn-state-up {
 base vn-state-type;
 description "VN state up";
}
identity vn-state-down {
 base vn-state-type;
 description "VN state down";
}
identity vn-admin-state-type {
```

```
 description
 "Base identity for VN admin states";
 }
 identity vn-admin-state-up {
 base vn-admin-state-type;
 description "VN administratively state up";
 }
 identity vn-admin-state-down {
 base vn-admin-state-type;
 description "VN administratively state down";
 }
 identity vn-compute-state-type {
 description
 "Base identity for compute states";
 }
 identity vn-compute-state-computing {
 base vn-compute-state-type;
 description
 "State path compute in progress";
 }
 identity vn-compute-state-computation-ok {
 base vn-compute-state-type;
 description
 "State path compute successful";
 }
 identity vn-compute-state-computatione-failed {
 base vn-compute-state-type;
 description
 "State path compute failed";
 }
}
/*
 * Groupings
 */

typedef vn-disjointness {
 type bits {
 bit node {
 position 0;
 description "node disjoint";
 }
 bit link {
 position 1;
 description "link disjoint";
 }
 bit srlg {
```



```
 position 2;
 description "srlg disjoint";
 }
}
description
 "type of the resource disjointness for
 VN level applied across all VN members
 in a VN";
}

grouping vn-ap {
 description
 "VNAP related information";
 leaf vn-ap-id {
 type uint32;
 description
 "unique identifier for the referred
 VNAP";
 }
 leaf vn {
 type leafref {
 path "/actn/vn/vn-list/vn-id";
 }
 description
 "reference to the VN";
 }
 leaf abstract-node {
 type leafref {
 path "/nw:networks/nw:network/nw:node/"
 + "tet:te-node-id";
 }
 description
 "a reference to the abstract node in TE
 Topology";
 }
 leaf ltp {
 type te-types:te-tp-id;
 description
 "Reference LTP in the TE-topology";
 }
}

grouping access-point {
 description
 "AP related information";
 leaf access-point-id {
```

```
 type uint32;
 description
 "unique identifier for the referred
 access point";
 }
 leaf access-point-name {
 type string;
 description
 "ap name";
 }

 leaf max-bandwidth {
 type te-types:te-bandwidth;
 description
 "max bandwidth of the AP";
 }
 leaf avl-bandwidth {
 type te-types:te-bandwidth;
 description
 "available bandwidth of the AP";
 }
 /*add details and any other properties of AP,
 not associated by a VN
 CE port, PE port etc.
 */
 list vn-ap {
 key vn-ap-id;
 uses vn-ap;
 description
 "list of VNAP in this AP";
 }
} //access-point
grouping vn-member {
 description
 "vn-member is described by this container";
 leaf vn-member-id {
 type uint32;
 description
 "vn-member identifier";
 }
}
container src
{
 description
 "the source of VN Member";
 leaf src {
```

```
 type leafref {
 path "/actn/ap/access-point-list/access-point-id";
 }
 description
 "reference to source AP";
 }
 leaf src-vn-ap-id{
 type leafref {
 path "/actn/ap/access-point-list/vn-ap/vn-ap-id";
 }
 description
 "reference to source VNAP";
 }
 leaf multi-src {
 if-feature multi-src-dest;
 type boolean;
 description
 "Is source part of multi-source, where
 only one of the source is enabled";
 }
}
container dest
{
 description
 "the destination of VN Member";
 leaf dest {
 type leafref {
 path "/actn/ap/access-point-list/access-point-id";
 }
 description
 "reference to destination AP";
 }
 leaf dest-vn-ap-id{
 type leafref {
 path "/actn/ap/access-point-list/vn-ap/vn-ap-id";
 }
 description
 "reference to dest VNAP";
 }
 leaf multi-dest {
 if-feature multi-src-dest;
 type boolean;
 description
 "Is destination part of multi-destination, where
 only one of the destination is enabled";
 }
}
```

```
 }
 }
 leaf connectivity-matrix-id{
 type leafref {
 path "/nw:networks/nw:network/nw:node/tet:te/"
 + "tet:te-node-attributes/"
 + "tet:connectivity-matrices/"
 + "tet:connectivity-matrix/tet:id";
 }
 description
 "reference to connectivity-matrix";
 }
} //vn-member
/*
grouping policy {
 description
 "policy related to vn-member-id";
 leaf local-reroute {
 type boolean;
 description
 "Policy to state if reroute
 can be done locally";
 }
 leaf push-allowed {
 type boolean;
 description
 "Policy to state if changes
 can be pushed to the customer";
 }
 leaf incremental-update {
 type boolean;
 description
 "Policy to allow only the
 changes to be reported";
 }
}
} //policy
*/
grouping vn-policy {
 description
 "policy for VN-level diverisity";
 leaf vn-level-diversity {
 type vn-disjointness;
 description
 "the type of disjointness on the VN level
 (i.e., across all VN members)";
 }
}
```

```

 }
 }
 /*
 grouping metrics-op {
 description
 "metric related information";
 list metric{
 key "metric-type";
 config false;
 description
 "The list of metrics for VN";
 leaf metric-type {
 type identityref {
 base te-types:path-metric-type;
 }
 description
 "The VN metric type.";
 }
 leaf value{
 type uint32;
 description
 "The limit value";
 }
 }
 }
 */
 /*
 grouping metrics {
 description
 "metric related information";
 list metric{
 key "metric-type";
 description
 "The list of metrics for VN";
 uses te:path-metrics-bounds_config;
 container optimize{
 description
 "optimizing constraints";
 leaf enabled{
 type boolean;
 description
 "Metric to optimize";
 }
 leaf value{
 type uint32;

```

```

 description
 "The computed value";
 }
}
}
}
/*
/*
grouping service-metric {
 description
 "service-metric";
 uses te:path-objective-function_config;
 uses metrics;
 uses te-types:common-constraints_config;
 uses te:protection-restoration-params_config;
 uses policy;
} //service-metric
/*
/*
* Configuration data nodes
*/
container actn {
 description
 "actn is described by this container";
 container ap {
 description
 "AP configurations";
 list access-point-list {
 key "access-point-id";
 description
 "access-point identifier";
 uses access-point {
 description
 "access-point information";
 }
 }
 }
}
container vn {
 description
 "VN configurations";
 list vn-list {
 key "vn-id";
 description
 "a virtual network is identified by a vn-id";
 leaf vn-id {

```

```
 type uint32;
 description
 "a unique vn identifier";
 }
 leaf vn-name {
 type string;
 description "vn name";
 }
 leaf vn-topology-id{
 type te-types:te-topology-id;
 description
 "An optional identifier to the TE Topology
 Model where the abstract nodes and links
 of the Topology can be found for Type 2
 VNS";
 }
 leaf abstract-node {
 type leafref {
 path "/nw:networks/nw:network/nw:node/"
 + "tet:te-node-id";
 }
 description
 "a reference to the abstract node in TE
 Topology";
 }
 list vn-member-list{
 key "vn-member-id";
 description
 "List of VN-members in a VN";
 uses vn-member;
 /*uses metrics-op;*/
 leaf oper-status {
 type identityref {
 base vn-state-type;
 }
 config false;
 description
 "VN-member operational state.";
 }
 }
}
leaf if-selected{
 if-feature multi-src-dest;
 type boolean;
 default false;
```

```

 config false;
 description
 "Is the vn-member is selected among the
 multi-src/dest options";
 }
/*
container multi-src-dest{
 if-feature multi-src-dest;
 config false;
 description
 "The selected VN Member when multi-src
 and/or multi-destination is enabled.";
 leaf selected-vn-member{
 type leafref {
 path "/actn/vn/vn-list/vn-member-list"
 + "/vn-member-id";
 }
 description
 "The selected VN Member along the set
 of source and destination configured
 with multi-source and/or multi-destination";
 }
}
*/
/*uses service-metric;*/
leaf admin-status {
 type identityref {
 base vn-admin-state-type;
 }
 default vn-admin-state-up;
 description "VN administrative state.";
}
leaf oper-status {
 type identityref {
 base vn-state-type;
 }
 config false;
 description "VN operational state.";
}
 uses vn-policy;
} //vn-list
} //vn
} //actn
/*
* Notifications - TBD

```



```
*/
/*
* RPC
*/
rpc vn-compute{
 description
 "The VN computation without actual
 instantiation";
 input {
 leaf abstract-node {
 type leafref {
 path "/nw:networks/nw:network/nw:node/"
 + "tet:te-node-id";
 }
 description
 "a reference to the abstract node in TE
 Topology";
 }
 list vn-member-list{
 key "vn-member-id";
 description
 "List of VN-members in a VN";
 uses vn-member;
 }
 uses vn-policy;
 /*uses service-metric;*/
 }
 output {
 list vn-member-list{
 key "vn-member-id";
 description
 "List of VN-members in a VN";
 uses vn-member;
 leaf if-selected{
 if-feature multi-src-dest;
 type boolean;
 default false;
 description
 "Is the vn-member is selected among
 the multi-src/dest options";
 }
 /*uses metrics-op;*/
 leaf compute-status {
 type identityref {
 base vn-compute-state-type;
 }
 }
 }
 }
}
```

```

 }
 description
 "VN-member compute state.";
 }
}
/*
container multi-src-dest{
 if-feature multi-src-dest;
 description
 "The selected VN Member when multi-src
 and/or mult-destination is enabled.";
 leaf selected-vn-member-id{
 type uint32;
 description
 "The selected VN Member-id from the
 input";
 }
}*/
}
}
}

```

<CODE ENDS>

## 7. JSON Example

This section provides json implementation examples as to how ACTN VN YANG model and TE topology model are used together to instantiate virtual networks.

The example in this section includes following VN

- o VN1 (Type 1): Which maps to the single node topology abstract1 (node D1) and consist of VN Members 104 (L1 to L4), 107 (L1 to L7), 204 (L2 to L4), 308 (L3 to L8) and 108 (L1 to L8). We also show how disjointness (node, link, srlg) is supported in the example on the global level (i.e., connectivity matrices level).

- o VN2 (Type 2): Which maps to the single node topology abstract2 (node D2), this topology has an underlay topology (absolute) (see figure in section 3.2). This VN has a single VN member 105 (L1 to L5) and an underlay path (S4 and S7) has been set in the connectivity matrix of abstract2 topology;
- o VN3 (Type 1): This VN has a multi-source, multi-destination feature enable for VN Member 104 (L1 to L4)/107 (L1 to L7) [multi-src] and VN Member 204 (L2 to L4)/304 (L3 to L4) [multi-dest] usecase. The selected VN-member is known via the field "if-selected" and the corresponding connectivity-matrix-id.

Note that the ACTN VN YANG model also include the AP and VNAP which shows various VN using the same AP.

#### 7.1. ACTN VN JSON

```
{
 "actn":{
 "ap":{
 "access-point-list": [
 {
 "access-point-id": 101,
 "access-point-name": "101",
 "vn-ap": [
 {
 "vn-ap-id": 10101,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "1-0-1"
 },
 {
 "vn-ap-id": 10102,
 "vn": 2,
 "abstract-node": "D2",
 "ltp": "1-0-1"
 },
 {
 "vn-ap-id": 10103,
 "vn": 3,
 "abstract-node": "D3",
 "ltp": "1-0-1"
 }
]
 },
 {
 "access-point-id": 202,
 "access-point-name": "202",
 "vn-ap": [
```

```
 {
 "vn-ap-id": 20201,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "2-0-2"
 }
],
},
{
 "access-point-id": 303,
 "access-point-name": "303",
 "vn-ap": [
 {
 "vn-ap-id": 30301,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "3-0-3"
 },
 {
 "vn-ap-id": 30303,
 "vn": 3,
 "abstract-node": "D3",
 "ltp": "3-0-3"
 }
]
},
{
 "access-point-id": 440,
 "access-point-name": "440",
 "vn-ap": [
 {
 "vn-ap-id": 44001,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "4-4-0"
 }
]
},
{
 "access-point-id": 550,
 "access-point-name": "550",
 "vn-ap": [
 {
 "vn-ap-id": 55002,
 "vn": 2,
 "abstract-node": "D2",
 "ltp": "5-5-0"
 }
]
}
```

```

 },
 {
 "access-point-id": 770,
 "access-point-name": "770",
 "vn-ap": [
 {
 "vn-ap-id": 77001,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "7-7-0"
 },
 {
 "vn-ap-id": 77003,
 "vn": 3,
 "abstract-node": "D3",
 "ltp": "7-7-0"
 }
]
 },
 {
 "access-point-id": 880,
 "access-point-name": "880",
 "vn-ap": [
 {
 "vn-ap-id": 88001,
 "vn": 1,
 "abstract-node": "D1",
 "ltp": "8-8-0"
 },
 {
 "vn-ap-id": 88003,
 "vn": 3,
 "abstract-node": "D3",
 "ltp": "8-8-0"
 }
]
 }
],
 "vn": {
 "vn-list": [
 {
 "vn-id": 1,
 "vn-name": "vn1",
 "vn-topology-id": "te-topology:abstract1",
 "abstract-node": "D1",
 "vn-member-list": [
 {
 "vn-member-id": 104,

```

```

 "src": {
 "src": 101,
 "src-vn-ap-id": 10101,
 },
 "dest": {
 "dest": 440,
 "dest-vn-ap-id": 44001,
 },
 "connectivity-matrix-id": 104
 },
 {
 "vn-member-id": 107,
 "src": {
 "src": 101,
 "src-vn-ap-id": 10101,
 },
 "dest": {
 "dest": 770,
 "dest-vn-ap-id": 77001,
 },
 "connectivity-matrix-id": 107
 },
 {
 "vn-member-id": 204,
 "src": {
 "src": 202,
 "dest-vn-ap-id": 20401,
 },
 "dest": {
 "dest": 440,
 "dest-vn-ap-id": 44001,
 },
 "connectivity-matrix-id": 204
 },
 {
 "vn-member-id": 308,
 "src": {
 "src": 303,
 "src-vn-ap-id": 30301,
 },
 "dest": {
 "dest": 880,
 "src-vn-ap-id": 88001,
 },
 "connectivity-matrix-id": 308
 },
 {
 "vn-member-id": 108,
 "src": {

```

```

 "src": 101,
 "src-vn-ap-id": 10101,
 },
 "dest": {
 "dest": 880,
 "dest-vn-ap-id": 88001,
 },
 "connectivity-matrix-id": 108
 }
]
},
{
 "vn-id": 2,
 "vn-name": "vn2",
 "vn-topology-id": "te-topology:abstract2",
 "abstract-node": "D2",
 "vn-member-list": [
 {
 "vn-member-id": 105,
 "src": {
 "src": 101,
 "src-vn-ap-id": 10102,
 },
 "dest": {
 "dest": 550,
 "dest-vn-ap-id": 55002,
 },
 "connectivity-matrix-id": 105
 }
]
},
{
 "vn-id": 3,
 "vn-name": "vn3",
 "vn-topology-id": "te-topology:abstract3",
 "abstract-node": "D3",
 "vn-member-list": [
 {
 "vn-member-id": 104,
 "src": {
 "src": 101,
 },
 "dest": {
 "dest": 440,
 "multi-dest": true
 }
 }
],
 {
 "vn-member-id": 107,

```

```

 "src": {
 "src": 101,
 "src-vn-ap-id": 10103,
 },
 "dest": {
 "dest": 770,
 "dest-vn-ap-id": 77003,
 "multi-dest": true
 },
 "connectivity-matrix-id": 107,
 "if-selected": true,
 },
 {
 "vn-member-id": 204,
 "src": {
 "src": 202,
 "multi-src": true,
 },
 "dest": {
 "dest": 440,
 },
 },
 {
 "vn-member-id": 304,
 "src": {
 "src": 303,
 "src-vn-ap-id": 30303,
 "multi-src": true,
 },
 "dest": {
 "dest": 440,
 "src-vn-ap-id": 44003,
 },
 "connectivity-matrix-id": 304,
 "if-selected": true,
 },
],
},
]
}
}
}

```

## 7.2. TE-topology JSON

```

{
 "networks": {

```



```
"network": [
 {
 "network-types": {
 "te-topology": {}
 },
 "network-id": "abstract1",
 "provider-id": 201,
 "client-id": 600,
 "te-topology-id": "te-topology:abstract1",
 "node": [
 {
 "node-id": "D1",
 "te-node-id": "2.0.1.1",
 "te": {
 "te-node-attributes": {
 "domain-id": 1,
 "is-abstract": [null],
 "connectivity-matrices": {
 "is-allowed": true,
 "path-constraints": {
 "bandwidth-generic": {
 "te-bandwidth": {
 "generic": [
 {
 "generic": "0x1p10",
 }
]
 }
 }
 }
 }
 }
 },
 "disjointness": "node link srlg",
 },
],
 "connectivity-matrix": [
 {
 "id": 104,
 "from": "1-0-1",
 "to": "4-4-0"
 },
 {
 "id": 107,
 "from": "1-0-1",
 "to": "7-7-0"
 },
 {
 "id": 204,
 "from": "2-0-2",
 "to": "4-4-0"
 },
]
 }
]
```

```

 "id": 308,
 "from": "3-0-3",
 "to": "8-8-0"
 },
 {
 "id": 108,
 "from": "1-0-1",
 "to": "8-8-0"
 }
],
 }
},
"termination-point": [
 {
 "tp-id": "1-0-1",
 "te-tp-id": 10001,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "1-1-0",
 "te-tp-id": 10100,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "2-0-2",
 "te-tp-id": 20002,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
]
}

```

```
 },
 {
 "tp-id": "2-2-0",
 "te-tp-id": 20200,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
],
 {
 "tp-id": "3-0-3",
 "te-tp-id": 30003,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
],
{
 "tp-id": "3-3-0",
 "te-tp-id": 30300,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
}
],
{
 "tp-id": "4-0-4",
 "te-tp-id": 40004,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
}
],
}
```



```
"tp-id": "6-6-0",
"te-tp-id": 60600,
"te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
},
{
 "tp-id": "7-0-7",
 "te-tp-id": 70007,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "7-7-0",
 "te-tp-id": 70700,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "8-0-8",
 "te-tp-id": 80008,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "8-8-0",
```

```

 "te-tp-id": 80800,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
]
},
{
 "network-types": {
 "te-topology": {}
 },
 "network-id": "abstract2",
 "provider-id": 201,
 "client-id": 600,
 "te-topology-id": "te-topology:abstract2",
 "node": [
 {
 "node-id": "D2",
 "te-node-id": "2.0.1.2",
 "te": {
 "te-node-attributes": {
 "domain-id": 1,
 "is-abstract": [null],
 "connectivity-matrices": {
 "is-allowed": true,
 "underlay": {
 "enabled": true
 }
 },
 "path-constraints": {
 "bandwidth-generic": {
 "te-bandwidth": {
 "generic": [
 {
 "generic": "0x1p10"
 }
]
 }
 }
 }
 },
 "optimizations": {
 "objective-function": {

```

```

 "objective-function-type": "of-maximize-residual-
bandwidth"
 }
 },
 "connectivity-matrix": [
 {
 "id": 105,
 "from": "1-0-1",
 "to": "5-5-0",
 "underlay": {
 "enabled": true,
 "primary-path": {
 "network-ref": "absolute",
 "path-element": [
 {
 "path-element-id": 1,
 "index": 1,
 "numbered-hop": {
 "address": "4.4.4.4",
 "hop-type": "STRICT"
 }
 },
 {
 "path-element-id": 2,
 "index": 2,
 "numbered-hop": {
 "address": "7.7.7.7",
 "hop-type": "STRICT"
 }
 }
]
 }
 }
 }
]
},
"termination-point": [
 {
 "tp-id": "1-0-1",
 "te-tp-id": 10001,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
]

```

```
 }
 },
 {
 "tp-id": "1-1-0",
 "te-tp-id": 10100,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "2-0-2",
 "te-tp-id": 20002,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "2-2-0",
 "te-tp-id": 20200,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "3-0-3",
 "te-tp-id": 30003,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
}
```



```
 },
 {
 "tp-id": "3-3-0",
 "te-tp-id": 30300,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
],
 {
 "tp-id": "4-0-4",
 "te-tp-id": 40004,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
],
{
 "tp-id": "4-4-0",
 "te-tp-id": 40400,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "5-0-5",
 "te-tp-id": 50005,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
}
```

```

{
 "tp-id": "5-5-0",
 "te-tp-id": 50500,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "6-0-6",
 "te-tp-id": 60006,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "6-6-0",
 "te-tp-id": 60600,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "7-0-7",
 "te-tp-id": 70007,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{

```

```

 "tp-id": "7-7-0",
 "te-tp-id": 70700,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "8-0-8",
 "te-tp-id": 80008,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "8-8-0",
 "te-tp-id": 80800,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
]
},
{
 "network-types": {
 "te-topology": {}
 },
 "network-id": "abstract3",
 "provider-id": 201,
 "client-id": 600,
 "te-topology-id": "te-topology:abstract3",
 "node": [
 {

```

```

"node-id": "D3",
"te-node-id": "3.0.1.1",
"te": {
 "te-node-attributes": {
 "domain-id" : 3,
 "is-abstract": [null],
 "connectivity-matrices": {
 "is-allowed": true,
 "path-constraints": {
 "bandwidth-generic": {
 "te-bandwidth": {
 "generic": [
 {
 "generic": "0x1p10",
 }
]
 }
 }
 },
 "connectivity-matrix": [
 {
 "id": 107,
 "from": "1-0-1",
 "to": "7-7-0"
 },
 {
 "id": 308,
 "from": "3-0-3",
 "to": "8-8-0"
 }
],
]
 }
},
"termination-point": [
 {
 "tp-id": "1-0-1",
 "te-tp-id": 10001,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
 },
 {
 "tp-id": "1-1-0",

```

```
"te-tp-id": 10100,
"te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
},
{
 "tp-id": "2-0-2",
 "te-tp-id": 20002,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "2-2-0",
 "te-tp-id": 20200,
 "te": {
 "interface-switching-capability": [
 {
 "switching-capability": "switching-otn",
 "encoding": "lsp-encoding-oduk"
 }
]
 }
},
{
 "tp-id": "3-0-3",
 "te-tp-id": 30003,
 "te": {
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```

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 {
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 "encoding": "lsp-encoding-oduk"
 }
]
 }
 }
]
}

```

## 8. Security Considerations

TDB



## 9. IANA Considerations

TDB

## 10. Acknowledgments

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## Traffic Engineering and Service Mapping Yang Model

draft-lee-teas-te-service-mapping-yang-13

### Abstract

This document provides a YANG data model to map customer service models (e.g., the L3VPM Service Model) to Traffic Engineering (TE) models (e.g., the TE Tunnel or the Abstraction and Control of Traffic Engineered Networks Virtual Network model). This model is referred to as TE Service Mapping Model and is applicable generically to the operator's need for seamless control and management of their VPN services with TE tunnel support.

The model is principally used to allow monitoring and diagnostics of the management systems to show how the service requests are mapped onto underlying network resource and TE models.

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## 1. Introduction

Data models are a representation of objects that can be configured or monitored within a system. Within the IETF, YANG [RFC6020] is the language of choice for documenting data models, and YANG models have been produced to allow configuration or modeling of a variety of network devices, protocol instances, and network services. YANG data models have been classified in [RFC8199] and [RFC8309].

Framework for Abstraction and Control of Traffic Engineered Networks (ACTN) [RFC8453] introduces an architecture to support virtual network services and connectivity services. [ACTN-VN-YANG] defines a YANG model and describes how customers or end-to-end orchestrators can request and/or instantiate a generic virtual network service. [ACTN-Applicability] describes the way IETF YANG models of different classifications can be applied to the ACTN interfaces. In particular, it describes how customer service models can be mapped into the CNC-MDSC Interface (CMI) of the ACTN architecture.

The models presented in this document are also applicable in generic context [RFC8309] as part of Customer Service Model used between Service Orchestrator and Customer.

[RFC8299] provides a L3VPN service delivery YANG model for PE-based VPNs. The scope of that draft is limited to a set of domains under control of the same network operator to deliver services requiring TE tunnels.

[L2SM] provides a L2VPN service delivery YANG model for PE-based VPNs. The scope of that draft is limited to a set of domains under control of the same network operator to deliver services requiring TE tunnels.

[L1CSM] provides a L1 connectivity service delivery YANG model for PE-based VPNs. The scope of that draft is limited to a set of domains under control of the same network operator to deliver services requiring TE tunnels.



While the IP/MPLS Provisioning Network Controller (PNC) is responsible for provisioning the VPN service on the Provider Edge (PE) nodes, the Multi-Domain Service Coordinator (MDSC) can coordinate how to map the VPN services onto Traffic Engineering (TE) tunnels. This is consistent with the two of the core functions of the MDSC specified in [RFC8453]:

- . Customer mapping/translation function: This function is to map customer requests/commands into network provisioning requests that can be sent to the PNC according to the business policies that have been provisioned statically or dynamically. Specifically, it provides mapping and translation of a customer's service request into a set of parameters that are specific to a network type and technology such that the network configuration process is made possible.
- . Virtual service coordination function: This function translates customer service-related information into virtual network service operations in order to seamlessly operate virtual networks while meeting a customer's service requirements. In the context of ACTN, service/virtual service coordination includes a number of service orchestration functions such as multi-destination load balancing, guarantees of service quality, bandwidth and throughput. It also includes notifications for service fault and performance degradation and so forth.

Section 2 describes a set of TE & service related parameters that this document addresses as new and advanced parameters that are not included in generic service models. Section 3 discusses YANG modeling approach.

### 1.1. Terminology

Refer to [RFC8453], [RFC7926], and [RFC8309] for the key terms used in this document.

### 1.2. Tree diagram

A simplified graphical representation of the data model is used in Section 5 of this this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

### 1.3. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the

corresponding YANG imported modules, as shown in Table 1.

| Prefix    | YANG module                   | Reference   |
|-----------|-------------------------------|-------------|
| tsm-types | ietf-te-service-mapping-types | [RFCXXXX]   |
| l1        | ietf-l1csm                    | [L1CSM]     |
| l2vpn-svc | ietf-l2vpn-svc                | [L2SM]      |
| l3vpn-svc | ietf-l3vpn-svc                | [RFC8299]   |
| l1-tsm    | ietf-l1csm-te-service-mapping | [RFCXXXX]   |
| l2-tsm    | ietf-l2sm-te-service-mapping  | [RFCXXXX]   |
| l3-tsm    | ietf-l3sm-te-service-mapping  | [RFCXXXX]   |
| vn        | ietf-vn                       | [ACTN-VN]   |
| nw        | ietf-network                  | [RFC8345]   |
| te-types  | ietf-te-types                 | [TE-Types]  |
| te-topo   | ietf-te-topology              | [TE-Topo]   |
| te        | ietf-te                       | [TE-Tunnel] |

Table 1: Prefixes and corresponding YANG modules

Note: The RFC Editor will replace XXXX with the number assigned to the RFC once this draft becomes an RFC.

## 2. TE & Service Related Parameters

While L1/2/3 service models [L1CSM, L2SM, L3SM] are intended to provide service-specific parameters for VPN service instances, there are a number of TE & Service related parameters that are not included in the generic service models.

Additional service parameters and policies that are not included in the aforementioned service models are addressed in the YANG models defined in this document.

### 2.1. VN/Tunnel Selection Requirements

In some cases, the service requirements may need addition TE tunnels to be established. This may occur when there are no suitable existing TE tunnels that can support the service requirements, or when the operator would like to dynamically create and bind tunnels to the VPN such that they are not shared by other VPNs, for example, for network slicing. The establishment of TE tunnels is subject to the network operator's policies.

To summarize, there are three modes of VN/Tunnel selection operations to be supported as follows. Additional modes may be defined in the future.

- o New VN/Tunnel Binding - A customer could request a VPN service based on VN/Tunnels that are not shared with other existing or future services. This might be to meet VPN isolation requirements. Further, the YANG model described in Section 5 of this document can be used to describe the mapping between the VPN service and the ACTN VN. The VN (and TE tunnels) could be bound to the VPN and not used for any other VPN.

Under this mode, the following sub-categories can be supported:

1. Hard Isolation with deterministic characteristics: A customer could request a VPN service using a set of TE Tunnels with deterministic characteristics requirements (e.g., no latency variation) and where that set of TE Tunnels must not be shared with other VPN services and must not compete for bandwidth or other network resources with other TE Tunnels.
  2. Hard Isolation: This is similar to the above case but without the deterministic characteristics requirements.
  3. Soft Isolation: The customer requests a VPN service using a set of TE tunnels which can be shared with other VPN services.
- o VN/Tunnel Sharing - A customer could request a VPN service where new tunnels (or a VN) do not need to be created for each VPN and can be shared across multiple VPNs. Further, the mapping YANG model described in Section 5 of this document can be used to describe the mapping between the VPN service and the tunnels in use. No modification of the properties of a tunnel (or VN) is allowed in this mode: an existing tunnel can only be selected.
  - o VN/Tunnel Modify - This mode allows the modification of the properties of the existing VN/tunnel (e.g., bandwidth).

## 2.2. Availability Requirement

Availability is another service requirement or intent that may influence the selection or provisioning of TE tunnels or a VN to support the requested service. Availability is a probabilistic measure of the length of time that a VPN/VN instance functions without a network failure.

The availability level will need to be translated into network specific policies such as the protection/reroute policy associated with a VN or Tunnel. The means by which this is achieved is not in the scope of this draft.

## 3. YANG Modeling Approach

This section provides how the TE & Service mapping parameters are supported using augmentation of the existing service models (i.e., [L1CSM], [L2SM], and [L3SM]). Figure 1 shows the scope of the Augmented LxSM Model.

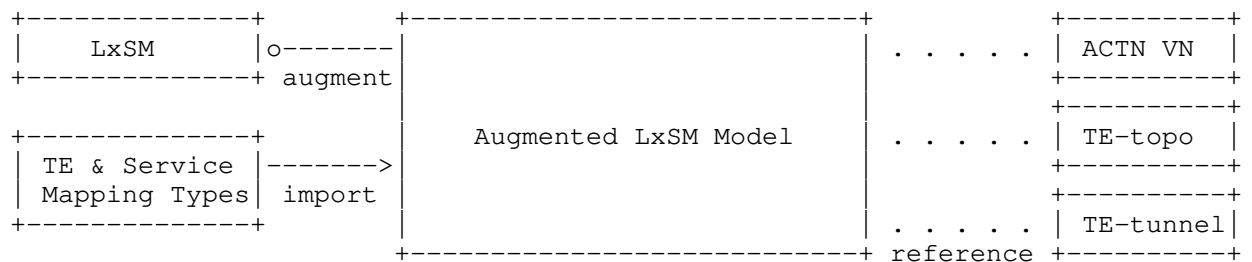


Figure 1. Augmented LxSM Model

The Augmented LxSM model (where x=1,2,3) augments the basic LxSM model while importing the common TE & Service related parameters (defined in Section 2) grouping information from TE & Service Mapping Types. The TE & Service Mapping Types (ietf-te-service-mapping-types) module is the repository of all common groupings imported by each augmented LxSM model. Any future service models would import this grouping file.

The role of the augmented LxSm service model is to expose the mapping relationship between service models and TE models so that VN/VPN service instantiations provided by the underlying TE networks

can be viewed outside of the MDSC, for example by an operator who is diagnosing the behavior of the network. It also allows for the customers to access operational state information about how their services are instantiated with the underlying VN, TE topology or TE tunnels provided that the MDSC operator is willing to share that information. This mapping will facilitate a seamless service management operation with underlay-TE network visibility.

As seen in Figure 1, the augmented LxSM service model records a mapping between the customer service models and the ACTN VN YANG model. Thus, when the MDSC receives a service request it creates a VN that meets the customer's service objectives with various constraints via TE-topology model [TE-topo], and this relationship is recorded by the Augmented LxSM Model. The model also supports a mapping between a service model and TE-topology or a TE-tunnel.

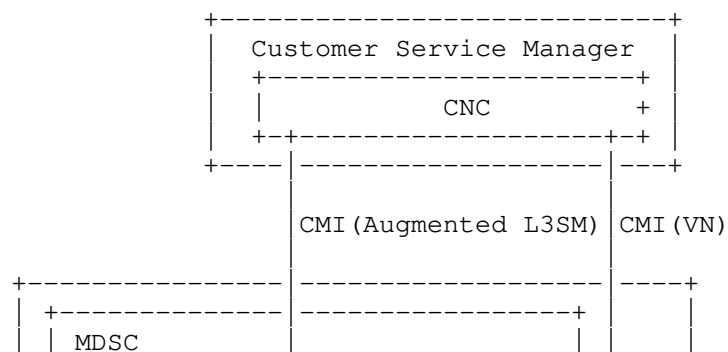
### 3.1. Forward Compatibility

The YANG module defined in this document supports three existing service models via augmenting while sharing the common TE & Service Mapping Types.

It is possible that new service models will be defined at some future time and that it will be desirable to map them to underlying TE constructs in the same way as the three existing models are augmented.

## 4. L3VPN Architecture in the ACTN Context

Figure 2 shows the architectural context of this document referencing the ACTN components and interfaces.



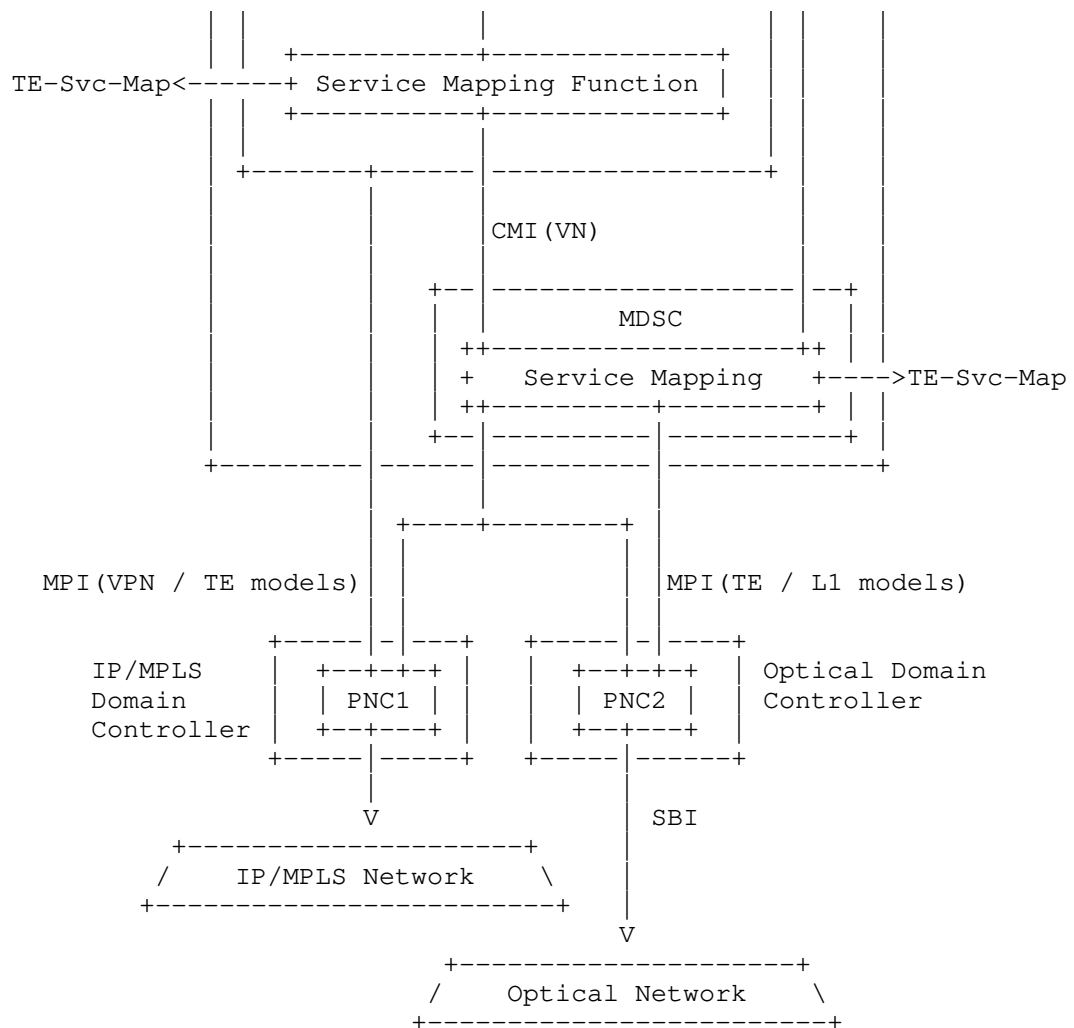


Figure 2: L3VPN Architecture from the IP+Optical Network Perspective

There are three main entities in the ACTN architecture and shown in Figure 2.

- . CNC: The Customer Network Controller is responsible for generating service requests. In the context of an L3VPN, the CNC uses the Augmented L3SM to express the service request and communicate it to the network operator.

- . MDSC: This entity is responsible for coordinating a L3VPN service request (expressed via the Augmented L3SM) with the IP/MPLS PNC and the Transport PNC. For TE services, one of the key responsibilities of the MDSC is to coordinate with both the IP PNC and the Transport PNC for the mapping of the Augmented L3VPN Service Model to the ACTN VN model. In the VN/TE-tunnel binding case, the MDSC will need to coordinate with the Transport PNC to dynamically create the TE-tunnels in the transport network as needed. These tunnels are added as links in the IP/MPLS Layer topology. The MDSC coordinates with IP/MPLS PNC to create the TE-tunnels in the IP/MPLS layer, as part of the ACTN VN creation.
- . PNC: The Provisioning Network Controller is responsible for configuring and operating the network devices. Figure 2 shows two distinct PNCs.
  - o IP/MPLS PNC (PNC1): This entity is responsible for device configuration to create PE-PE L3VPN tunnels for the VPN customer and for the configuration of the L3VPN VRF on the PE nodes. Each network element would select a tunnel based on the configuration.
  - o Transport PNC (PNC2): This entity is responsible for device configuration for TE tunnels in the transport networks.

There are four main interfaces shown in Figure 2.

- . CMI: The CNC-MDSC Interface is used to communicate service requests from the customer to the operator. The requests may be expressed as Augmented VPN service requests (L2SM, L3SM), as connectivity requests (L1CSM), or as virtual network requests (ACTN VN).
- . MPI: The MDSC-PNC Interface is used by the MDSC to orchestrate networks under the control of PNCs. The requests on this interface may use TE tunnel models, TE topology models, VPN network configuration models or layer one connectivity models.
- . SBI: The Southbound Interface is used by the PNC to control network devices and is out of scope for this document.
- . The TE Service Mapping Model as described in this document can be used to see the mapping between service models and VN models and TE Tunnel/Topology models. That mapping may occur in the CNC if a service request is mapped to a VN request. Or it may occur in the MDSC where a service request is mapped to a TE tunnel, TE topology, or VPN network configuration model. The TE Service Mapping Model may be read from the CNC or MDSC to understand how the mapping has been made and to see the purpose for which network resources are used.

As shown in Figure 2, the MDSC may be used recursively. For example, the CNC might map a L3SM request to a VN request that it sends to a recursive MDSC.

The high-level control flows for one example are as follows:

1. A customer asks for an L3VPN between CE1 and CE2 using the Augmented L3SM model.
2. The MDSC considers the service request and local policy to determine if it needs to create a new VN or any TE Topology, and if that is the case, ACTN VN YANG [ACTN-VN-YANG] is used to configure a new VN based on this VPN and map the VPN service to the ACTN VN. In case an existing tunnel is to be used, each device will select which tunnel to use and populate this mapping information.
3. The MDSC interacts with both the IP/MPLS PNC and the Transport PNC to create a PE-PE tunnel in the IP network mapped to a TE tunnel in the transport network by providing the inter-layer access points and tunnel requirements. The specific service information is passed to the IP/MPLS PNC for the actual VPN configuration and activation.
  - a. The Transport PNC creates the corresponding TE tunnel matching with the access point and egress point.
  - b. The IP/MPLS PNC maps the VPN ID with the corresponding TE tunnel ID to bind these two IDs.
4. The IP/MPLS PNC creates/updates a VRF instance for this VPN customer. This is not in the scope of this document.

#### 4.1. Service Mapping

Augmented L3SM and L2SM can be used to request VPN service creation including the creation of sites and corresponding site network access connection between CE and PE. A VPN-ID is used to identify each VPN service ordered by the customer. The ACTN VN can be used further to establish PE-to-PE connectivity between VPN sites belonging to the same VPN service. A VN-ID is used to identify each virtual network established between VPN sites.

Once the ACTN VN has been established over the TE network (maybe a new VN, maybe modification of an existing VN, or maybe the use of an unmodified existing VN), the mapping between the VPN service and the ACTN VN service can be created.



## 4.2. Site Mapping

The elements in Augmented L3SM and L2SM define site location parameters and constraints such as distance and access diversity that can influence the placement of network attachment points (i.e., virtual network access points (VNAP)). To achieve this, a central directory can be set up to establish the mapping between location parameters and constraints and network attachment point location. Suppose multiple attachment points are matched, the management system can use constraints or other local policy to select the best candidate network attachment points.

After a network attachment point is selected, the mapping between VPN site and VNAP can be established as shown in Table 1.

| Site  | Site Network Access | Location<br>(Address, Postal Code, State, City, Country Code) | Access Diversity<br>(Constraint-Type, Group-id, Target Group-id) | PE  |
|-------|---------------------|---------------------------------------------------------------|------------------------------------------------------------------|-----|
| SITE1 | ACCESS1             | (,,US,NewYork,)                                               | (10,PE-Diverse,10)                                               | PE1 |
| SITE2 | ACCESS2             | (,,CN,Beijing,)                                               | (10,PE-Diverse,10)                                               | PE2 |
| SITE3 | ACCESS3             | (,,UK,London, )                                               | (12,same-PE,12)                                                  | PE4 |
| SITE4 | ACCESS4             | (,,FR,Paris,)                                                 | (20,Bearer-Diverse,20)                                           | PE7 |

Table 1 : Mapping Between VPN Site and VNAP

## 5. Applicability of TE-Service Mapping in Generic context

As discussed in the Introduction Section, the models presented in this document are also applicable generically outside of the ACTN architecture. [RFC8309] defines Customer Service Model between Customer and Service Orchestrator and Service Delivery Model between Service Orchestrator and Network Orchestrator(s). TE-Service mapping models defined in this document can be regarded primarily as Customer Service Model and secondarily as Service Deliver Model.

## 6. YANG Data Trees

```

module: ietf-l1csm-te-service-mapping
 augment /l1:l1-connectivity/l1:services/l1:service:
 +-rw te-service-mapping!
 augment /l1:l1-connectivity/l1:services/l1:service:
 +-rw te-mapping
 +-rw map-type? identityref
 +-rw availability-type? identityref
 +-rw (te)?
 +--:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/vn/vn-list/vn-id
 +--:(te-topo)
 | +-rw vn-topology-id? te-types:te-topology-id
 | +-rw abstract-node? -> /nw:networks/network/node/node-id
 +--:(te-tunnel)
 +-rw te-tunnel-list* te:tunnel-ref
 augment /l1:l1-connectivity/l1:services/l1:service/l1:endpoint-1:
 +-rw (te)?
 +--:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/ap/access-point-list/access-point-id
 +--:(te)
 +-rw ltp? te-types:te-tp-id
 augment /l1:l1-connectivity/l1:services/l1:service/l1:endpoint-2:
 +-rw (te)?
 +--:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/ap/access-point-list/access-point-id
 +--:(te)
 +-rw ltp? te-types:te-tp-id

module: ietf-l2sm-te-service-mapping
 augment /l2vpn-svc:l2vpn-svc/l2vpn-svc:vpn-services/l2vpn-svc:vpn-service:
 +-rw te-service-mapping!
 augment /l2vpn-svc:l2vpn-svc/l2vpn-svc:vpn-services/l2vpn-svc:vpn-service:
 +-rw te-mapping
 +-rw map-type? identityref
 +-rw availability-type? identityref
 +-rw (te)?
 +--:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/vn/vn-list/vn-id
 +--:(te-topo)
 | +-rw vn-topology-id? te-types:te-topology-id
 | +-rw abstract-node? -> /nw:networks/network/node/node-id
 +--:(te-tunnel)
 +-rw te-tunnel-list* te:tunnel-ref

```

```

 augment /l2vpn-svc:l2vpn-svc/l2vpn-svc:sites/l2vpn-svc:site/l2vpn-svc:site-net
work-
accesses/l2vpn-svc:site-network-access:
 +-rw (te)?
 +-:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/ap/access-point-list/access-point-id
 +-:(te)
 | +-rw ltp? te-types:te-tp-id

module: ietf-l3sm-te-service-mapping
 augment /l3vpn-svc:l3vpn-svc/l3vpn-svc:vpn-services/l3vpn-svc:vpn-service:
 +-rw te-service-mapping!
 augment /l3vpn-svc:l3vpn-svc/l3vpn-svc:vpn-services/l3vpn-svc:vpn-service:
 +-rw te-mapping
 +-rw map-type? identityref
 +-rw availability-type? identityref
 +-rw (te)?
 +-:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/vn/vn-list/vn-id
 +-:(te-topo)
 | +-rw vn-topology-id? te-types:te-topology-id
 | +-rw abstract-node? -> /nw:networks/network/node/node-id
 +-:(te-tunnel)
 | +-rw te-tunnel-list* te:tunnel-ref
 augment /l3vpn-svc:l3vpn-svc/l3vpn-svc:sites/l3vpn-svc:site/l3vpn-svc:site-
network-accesses/l3vpn-svc:site-network-access:
 +-rw (te)?
 +-:(actn-vn)
 | +-rw actn-vn-ref? -> /vn:actn/ap/access-point-list/access-point-i
d
 +-:(te)
 | +-rw ltp? te-types:te-tp-id

```

## 7. YANG Data Models

The YANG codes are as follows:

```
<CODE BEGINS> file "ietf-te-service-mapping-types@2018-12-30.yang"
```

```

module ietf-te-service-mapping-types {

 namespace "urn:ietf:params:xml:ns:yang:ietf-te-service-mapping-types";

 prefix "tsm";

 import ietf-te-types {
 prefix "te-types";
 }

```

```
 }

 import ietf-network {
 prefix "nw";
 }

 import ietf-te {
 prefix "te";
 }

 import ietf-vn {
 prefix "vn";
 }

 organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

 contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Dhruv Dhody <dhruv.ietf@gmail.com>
 Qin Wu <bill.wu@huawei.com>";

 description
 "This module contains a YANG module for TE & Service mapping
 parameters and policies as a common grouping applicable to
 various service models (e.g., L1CSM, L2SM, L3SM, etc.)";

 revision 2018-12-30 {
 description
 "initial version.";
 reference
 "TBD";
 }

 /*
 * Identity for map-type
 */
 identity map-type {
 description
 "Base identity from which specific map types are
 derived.";
 }

 identity new {
 base map-type;
 description
 "The new VN/tunnels are binded to the service.";
 }
```

```
identity detnet-hard-isolation {
 base new;
 description
 "Hard isolation with deterministic characteristics.";
}

identity hard-isolation {
 base new;
 description
 "Hard isolation.";
}

identity soft-isolation {
 base new;
 description
 "Soft-isolation.";
}

identity select {
 base map-type;
 description
 "The VPN service selects an existing tunnel with no
 modification.";
}

identity modify {
 base map-type;
 description
 "The VPN service selects an existing tunnel and allows
 to modify the properties of the tunnel (e.g., b/w)";
}

/*
 * Identity for availability-type
 */
identity availability-type {
 description
 "Base identity from which specific map types are
 derived.";
}

identity level-1 {
 base availability-type;
 description
 "level 1: 99.9999%";
}

identity level-2 {
```

```
 base availability-type;
 description
 "level 2: 99.999%";
 }

 identity level-3 {
 base availability-type;
 description
 "level 3: 99.99%";
 }

 identity level-4 {
 base availability-type;
 description
 "level 4: 99.9%";
 }

 identity level-5 {
 base availability-type;
 description
 "level 5: 99%";
 }

 /*
 * Groupings
 */

 grouping te-ref {
 description
 "The reference to TE.";
 choice te {
 description
 "The TE";
 case actn-vn {
 leaf actn-vn-ref {
 type leafref {
 path "/vn:actn/vn:vn/vn:vn-list/vn:vn-id";
 }
 description
 "The reference to ACTN VN";
 }
 }
 case te-topo {
 leaf vn-topology-id {
 type te-types:te-topology-id;
 description
 "An identifier to the TE Topology Model
 where the abstract nodes and links of
 the Topology can be found for Type 2";
 }
 }
 }
 }
}
```

```

 VNS";
 }
 leaf abstract-node {
 type leafref {
 path "/nw:networks/nw:network/nw:node/"
 + "nw:node-id";
 }
 description
 "a reference to the abstract node in TE
 Topology";
 }
}
case te-tunnel {
 leaf-list te-tunnel-list {
 type te:tunnel-ref;
 description
 "Reference to TE Tunnels";
 }
}

}

grouping te-endpoint-ref {
 description
 "The reference to TE endpoints.";
 choice te {
 description
 "The TE";
 case actn-vn {
 leaf actn-vn-ref {
 type leafref {
 path "/vn:actn/vn:ap/vn:access-point-list"
 + "/vn:access-point-id";
 }
 description
 "The reference to ACTN VN";
 }
 }
 case te {
 leaf ltp {
 type te-types:te-tp-id;
 description
 "Reference LTP in the TE-topology";
 }
 }
 }
}

```

```
 }

 grouping te-mapping {
 description
 "Mapping between Services and TE";
 container te-mapping {
 description
 "Mapping between Services and TE";
 leaf map-type {
 type identityref {
 base map-type;
 }
 description
 "Isolation Requirements, Tunnel Bind or
 Tunnel Selection";
 }
 leaf availability-type {
 type identityref {
 base availability-type;
 }
 description
 "Availability Requirement for the Service";
 }
 uses te-ref;
 }
 }
 }
}
<CODE ENDS>
```

<CODE BEGINS> file "ietf-llcsm-te-service-mapping@2018-10-05.yang"

```
module ietf-llcsm-te-service-mapping {

 namespace "urn:ietf:params:xml:ns:yang:ietf-llcsm-te-service-mapping";

 prefix "tm";

 import ietf-te-service-mapping-types {
 prefix "tsm-types";
 }

 import ietf-llcsm {
 prefix "ll";
 }
}
```



```
organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Dhruv Dhody <dhruv.ietf@gmail.com>
 Qin Wu <bill.wu@huawei.com>";
description
 "This module contains a YANG module for the mapping of
 Layer 1 Connectivity Service Module (L1CSM) to the TE and VN ";

revision 2018-10-05 {
 description
 "initial version.";
 reference
 "TBD";
}

/*
 * Configuration data nodes
 */
augment "/l1:l1-connectivity/l1:services/l1:service" {
 description
 "l1csm augmented to include TE parameters and mapping";
 container te-service-mapping {
 presence "indicates l1 service to te mapping";
 description
 "Container to augment l1csm to TE parameters and mapping";
 }
}

augment "/l1:l1-connectivity/l1:services/l1:service" {
 description
 "This augment is only valid for TE mapping --
 te mapping is added";
 uses tsm-types:te-mapping;
}

augment "/l1:l1-connectivity/l1:services/l1:service/l1:endpoint-1" {
 description
 "This augment is only valid for TE mapping --
 endpoint-1 te-reference is added";
 uses tsm-types:te-endpoint-ref;
}

augment "/l1:l1-connectivity/l1:services/l1:service/l1:endpoint-2" {
 description
```

```
 "This augment is only valid for TE mapping --
 endpoint-2 te-reference is added";
 uses tsm-types:te-endpoint-ref;
}
}
```

<CODE ENDS>

<CODE BEGINS> file "ietf-l2sm-te-service-mapping@2018-10-05.yang"

```
module ietf-l2sm-te-service-mapping {

 namespace "urn:ietf:params:xml:ns:yang:ietf-l2sm-te-service-mapping";

 prefix "tm";

 import ietf-te-service-mapping-types {
 prefix "tsm-types";
 }

 import ietf-l2vpn-svc {
 prefix "l2vpn-svc";
 }

 organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

 contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Dhruv Dhody <dhruv.ietf@gmail.com>
 Qin Wu <bill.wu@huawei.com>";
 description
 "This module contains a YANG module for the mapping of
 Layer 2 Service Model (L1CSM) to the TE and VN ";

 revision 2018-10-05 {
 description
 "initial version.";
 reference
 "TBD";
 }
}
```

```
 /*
 * Configuration data nodes
 */
 augment "/l2vpn-svc:l2vpn-svc/l2vpn-svc:vpn-services/l2vpn-svc:vpn-servi
ce" {
 description
 "l2sm augmented to include TE parameters and mapping";
 container te-service-mapping {
 presence "indicates l2 service to te mapping";
 description
 "Container to augment l2sm to TE parameters and mapping";
 }
 }

 augment "/l2vpn-svc:l2vpn-svc/l2vpn-svc:vpn-services/l2vpn-svc:vpn-servi
ce" {
 description
 "This augment is only valid for TE mapping --
 te mapping is added";
 uses tsm-types:te-mapping;
 }

 augment "/l2vpn-svc:l2vpn-svc/l2vpn-svc:sites/l2vpn-svc:site"
 +"/l2vpn-svc:site-network-accesses/l2vpn-svc:site-network-access" {
 description
 "This augment is only valid for TE mapping --
 network-access te-reference is added";
 uses tsm-types:te-endpoint-ref;
 }
}
```

<CODE ENDS>

<CODE BEGINS> file "ietf-l3sm-te-service-mapping@2018-10-05.yang"

```
module ietf-l3sm-te-service-mapping {

 namespace "urn:ietf:params:xml:ns:yang:ietf-l3sm-te-service-mapping";

 prefix "tm";

 import ietf-te-service-mapping-types {
 prefix "tsm-types";
 }
}
```

```

 }

 import ietf-l3vpn-svc {
 prefix "l3vpn-svc";
 }

 organization
 "IETF Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

 contact
 "Editor: Young Lee <leeyoung@huawei.com>
 Dhruv Dhody <dhruv.ietf@gmail.com>
 Qin Wu <bill.wu@huawei.com>";

 description
 "This module contains a YANG module for the mapping of
 Layer 3 Service Model (L3SM) to the TE and VN ";

 revision 2018-10-05 {
 description
 "initial version.";
 reference
 "TBD";
 }

 /*
 * Configuration data nodes
 */
 augment "/l3vpn-svc:l3vpn-svc/l3vpn-svc:vpn-services/l3vpn-svc:vpn-servic
e" {
 description
 "l3sm augmented to include TE parameters and mapping";
 container te-service-mapping {
 presence "indicates l3 service to te mapping";
 description
 "Container to augment l3sm to TE parameters and mapping";
 }
 }

 augment "/l3vpn-svc:l3vpn-svc/l3vpn-svc:vpn-services/l3vpn-svc:vpn-servic
e" {
 description
 "This augment is only valid for TE mapping --
 te mapping is added";
 uses tsm-types:te-mapping;
 }

 augment "/l3vpn-svc:l3vpn-svc/l3vpn-svc:sites/l3vpn-svc:site"
 +"/l3vpn-svc:site-network-accesses/l3vpn-svc:site-network-access" {

```

```
 description
 "This augment is only valid for TE mapping --
 network-access te-reference is added";
 uses tsm-types:te-endpoint-ref;
 }
}
```

<CODE ENDS>

## 8. Security

The configuration, state, and action data defined in this document are designed to be accessed via a management protocol with a secure transport layer, such as NETCONF [RFC6241]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a preconfigured subset of all available NETCONF protocol operations and content.

A number of configuration data nodes defined in this document are writable/deletable (i.e., "config true") These data nodes may be considered sensitive or vulnerable in some network environments.

## 9. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```

URI: urn:ietf:params:xml:ns:yang:ietf-te-service-mapping-types
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-llcsm-te-service-mapping
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-l2sm-te-service-mapping
Registrant Contact: The IESG.

```

XML: N/A, the requested URI is an XML namespace.

---

---

URI: urn:ietf:params:xml:ns:yang:ietf-l3sm-te-service-mapping  
Registrant Contact: The IESG.  
XML: N/A, the requested URI is an XML namespace.

---

This document registers the following YANG modules in the YANG Module.

Names registry [RFC7950]:

---

name: ietf-te-service-mapping-types  
namespace: urn:ietf:params:xml:ns:yang:ietf-te-service-mapping-types  
reference: RFC XXXX (TDB)

---

---

name: ietf-l1csm-te-service-mapping  
namespace: urn:ietf:params:xml:ns:yang:ietf-l1csm-te-service-mapping  
reference: RFC XXXX (TDB)

---

---

name: ietf-l2sm-te-service-mapping  
namespace: urn:ietf:params:xml:ns:yang:ietf-l2sm-te-service-mapping  
reference: RFC XXXX (TDB)

---

---

name: ietf-l3sm-te-service-mapping  
namespace: urn:ietf:params:xml:ns:yang:ietf-l3sm-te-service-mapping  
reference: RFC XXXX (TDB)

---

## 10. Acknowledgements

We thank Diego Caviglia and Igor Bryskin for useful discussions and motivation for this work.

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- [L1CSM] G. Fioccola, et al, "A Yang Data Model for L1 Connectivity Service Model (L1CSM)", draft-ietf-ccamp-l1csm-yang, work in progress.

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YANG Data Model for Layer 3 TE Topologies  
draft-liu-teas-yang-l3-te-topo-05

Abstract

This document defines a YANG data model for layer 3 traffic engineering topologies.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of BCP 78 and BCP 79.

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## 1. Introduction

This document defines a YANG [RFC7950] data model for describing the relationship between a layer 3 network topology [I-D.ietf-i2rs-yang-l3-topology] and a TE topology [I-D.ietf-teas-yang-te-top].

When traffic engineering is enabled on a layer 3 network topology, there will be a corresponding TE topology. The TE topology may or may not be congruent to the layer 3 network topology. When such a congruent TE topology exists, there will be a one-to-one association between the one modeling element in the layer 3 topology to another element in the TE topology. When such a congruent TE topology does not exist, the association will not be one-to-one. This YANG data model allows both cases.

### 1.1. Terminology

The keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14, [RFC2119].

The following terms are defined in [RFC7950] and are not redefined here:

- o augment
- o data model
- o data node

## 2. Modeling Considerations

### 2.1. Relationship Between Layer 3 Topology and TE topology

In general, layer 3 network topology model and TE topology model can be used independently. When traffic engineering is enabled on a layer 3 network topology, there will be associations between objects in layer 3 network topologies and objects in TE topologies. The properties of these relations are:

- o The associations are between objects of the same class, i.e. node to node or link to link.
- o The multiplicity of such an association is: 0..1 to 0..1. An object in a layer 3 network may have zero or one associated object in the corresponding TE network.

### 2.2. Relationship Modeling

YANG data type leafref is used to model the association relationship between a layer 3 network topology and a TE topology. YANG must statements are used to enforce the referenced objects are in the topologies of proper type.

## 3. Model Structure

### 3.1. Layer 3 TE Topology Module

The model tree structure of the layer 3 TE topology module is as shown below:

```

module: ietf-l3-te-topology
 augment /nd:networks/nd:network/nd:network-types
 /l3t:l3-unicast-topology:
 +--rw l3-te!
 augment /nd:networks/nd:network/l3t:l3-topology-attributes:
 +--rw l3-te-topology-attributes
 +--rw network-ref? -> /nw:networks/network/network-id
 augment /nd:networks/nd:network/nd:node/l3t:l3-node-attributes:
 +--rw l3-te-node-attributes
 +--rw node-ref? -> /nw:networks
/network[nw:network-id=current()/../network-ref]/node/node-id
 +--rw network-ref? -> /nw:networks/network/network-id
 augment /nd:networks/nd:network/nd:node/lnk:termination-point
 /l3t:l3-termination-point-attributes:
 +--rw l3-te-tp-attributes
 +--rw tp-ref? -> /nw:networks
/network[nw:network-id=current()/../network-ref]
/node[nw:node-id=current()/../node-ref]/nt:termination-point/tp-id
 +--rw node-ref? -> /nw:networks
/network[nw:network-id=current()/../network-ref]/node/node-id
 +--rw network-ref? -> /nw:networks/network/network-id
 augment /nd:networks/nd:network/lnk:link/l3t:l3-link-attributes:
 +--rw l3-te-link-attributes
 +--rw link-ref? -> /nw:networks
/network[nw:network-id=current()/../network-ref]/nt:link/link-id
 +--rw network-ref? -> /nw:networks/network/network-id

```

### 3.2. Packet Switching TE Topology Module

This is an augmentation to base TE topology model.

```

module: ietf-te-topology-packet
 augment /nd:networks/nd:network/nd:node/tet:te
 /tet:te-node-attributes/tet:connectivity-matrices:
 +--rw performance-metric
 +--rw measurement
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32

```

```

 +--rw normality
 | +--rw unidirectional-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-min-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-max-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--rw unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--rw throttle
 | +--rw unidirectional-delay-offset? uint32
 | +--rw measure-interval? uint32
 | +--rw advertisement-interval? uint32
 | +--rw suppression-interval? uint32
 | +--rw threshold-out
 | | +--rw unidirectional-delay? uint32
 | | +--rw unidirectional-min-delay? uint32
 | | +--rw unidirectional-max-delay? uint32
 | | +--rw unidirectional-delay-variation? uint32
 | | +--rw unidirectional-packet-loss? decimal64
 | | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw threshold-in
 | | +--rw unidirectional-delay? uint32
 | | +--rw unidirectional-min-delay? uint32
 | | +--rw unidirectional-max-delay? uint32
 | | +--rw unidirectional-delay-variation? uint32
 | | +--rw unidirectional-packet-loss? decimal64
 | | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw threshold-accelerated-advertisement
 | | +--rw unidirectional-delay? uint32

```

```

 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/nd:node/tet:te
/tet:te-node-attributes/tet:connectivity-matrices
/tet:connectivity-matrix:
 +--rw performance-metric
 +--rw measurement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw normality
 +--rw unidirectional-delay? uint32
te-types:performance-metric-normality
 +--rw unidirectional-min-delay? uint32
te-types:performance-metric-normality
 +--rw unidirectional-max-delay? uint32
te-types:performance-metric-normality
 +--rw unidirectional-delay-variation? uint32
te-types:performance-metric-normality
 +--rw unidirectional-packet-loss? decimal64
te-types:performance-metric-normality
 +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 +--rw unidirectional-available-bandwidth?
te-types:performance-metric-normality
 +--rw unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--rw throttle
 +--rw unidirectional-delay-offset? uint32
 +--rw measure-interval? uint32
 +--rw advertisement-interval? uint32
 +--rw suppression-interval? uint32

```



```

 +--rw threshold-out
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-in
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-accelerated-advertisement
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/nd:node/tet:te
/tet:information-source-entry/tet:connectivity-matrices:
 +--ro performance-metric
 | +--ro measurement
 | | +--ro unidirectional-delay? uint32
 | | +--ro unidirectional-min-delay? uint32
 | | +--ro unidirectional-max-delay? uint32
 | | +--ro unidirectional-delay-variation? uint32
 | | +--ro unidirectional-packet-loss? decimal64
 | | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?

```

```

rt-types:bandwidth-ieee-float32
| +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro normality
| | +--ro unidirectional-delay?
te-types:performance-metric-normality
| | +--ro unidirectional-min-delay?
te-types:performance-metric-normality
| | +--ro unidirectional-max-delay?
te-types:performance-metric-normality
| | +--ro unidirectional-delay-variation?
te-types:performance-metric-normality
| | +--ro unidirectional-packet-loss?
te-types:performance-metric-normality
| | +--ro unidirectional-residual-bandwidth?
te-types:performance-metric-normality
| | +--ro unidirectional-available-bandwidth?
te-types:performance-metric-normality
| | +--ro unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
| +--ro throttle
| | +--ro unidirectional-delay-offset? uint32
| | +--ro measure-interval? uint32
| | +--ro advertisement-interval? uint32
| | +--ro suppression-interval? uint32
| | +--ro threshold-out
| | | +--ro unidirectional-delay? uint32
| | | +--ro unidirectional-min-delay? uint32
| | | +--ro unidirectional-max-delay? uint32
| | | +--ro unidirectional-delay-variation? uint32
| | | +--ro unidirectional-packet-loss? decimal64
| | | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro threshold-in
| | +--ro unidirectional-delay? uint32
| | +--ro unidirectional-min-delay? uint32
| | +--ro unidirectional-max-delay? uint32
| | +--ro unidirectional-delay-variation? uint32
| | +--ro unidirectional-packet-loss? decimal64
| | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
| +--ro unidirectional-utilized-bandwidth?

```

```

rt-types:bandwidth-ieee-float32
 +--ro threshold-accelerated-advertisement
 +--ro unidirectional-delay? uint32
 +--ro unidirectional-min-delay? uint32
 +--ro unidirectional-max-delay? uint32
 +--ro unidirectional-delay-variation? uint32
 +--ro unidirectional-packet-loss? decimal64
 +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/nd:node/tet:te
/tet:information-source-entry/tet:connectivity-matrices
/tet:connectivity-matrix:
 +--ro performance-metric
 +--ro measurement
 | +--ro unidirectional-delay? uint32
 | +--ro unidirectional-min-delay? uint32
 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro normality
 | +--ro unidirectional-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-min-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-max-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--ro unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--ro unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--ro unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--ro unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--ro throttle
 +--ro unidirectional-delay-offset? uint32

```

```

 +--ro measure-interval? uint32
 +--ro advertisement-interval? uint32
 +--ro suppression-interval? uint32
 +--ro threshold-out
 | +--ro unidirectional-delay? uint32
 | +--ro unidirectional-min-delay? uint32
 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro threshold-in
 | +--ro unidirectional-delay? uint32
 | +--ro unidirectional-min-delay? uint32
 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro threshold-accelerated-advertisement
 | +--ro unidirectional-delay? uint32
 | +--ro unidirectional-min-delay? uint32
 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/nd:node/tet:te
/tet:tunnel-termination-point/tet:local-link-connectivities:
 +--rw performance-metric
 +--rw measurement
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64

```

```

 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw normality
 | +--rw unidirectional-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-min-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-max-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--rw unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--rw throttle
 +--rw unidirectional-delay-offset? uint32
 +--rw measure-interval? uint32
 +--rw advertisement-interval? uint32
 +--rw suppression-interval? uint32
 +--rw threshold-out
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-in
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32

```

```

 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-accelerated-advertisement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/nd:node/tet:te
/tet:tunnel-termination-point/tet:local-link-connectivities
/tet:local-link-connectivity:
 +--rw performance-metric
 +--rw measurement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw normality
 +--rw unidirectional-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-min-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-max-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--rw unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-utilized-bandwidth?

```

```

te-types:performance-metric-normality
 +--rw throttle
 +--rw unidirectional-delay-offset? uint32
 +--rw measure-interval? uint32
 +--rw advertisement-interval? uint32
 +--rw suppression-interval? uint32
 +--rw threshold-out
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-in
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-accelerated-advertisement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/tet:te/tet:templates/tet:link-template
/tet:te-link-attributes:
 +--rw performance-metric
 +--rw measurement
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32

```

```

 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw normality
 | +--rw unidirectional-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-min-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-max-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--rw unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--rw throttle
 +--rw unidirectional-delay-offset? uint32
 +--rw measure-interval? uint32
 +--rw advertisement-interval? uint32
 +--rw suppression-interval? uint32
 +--rw threshold-out
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-in
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32

```



```

 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-accelerated-advertisement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/lnk:link/tet:te
/tet:te-link-attributes:
 +--rw performance-metric
 +--rw measurement
 | +--rw unidirectional-delay? uint32
 | +--rw unidirectional-min-delay? uint32
 | +--rw unidirectional-max-delay? uint32
 | +--rw unidirectional-delay-variation? uint32
 | +--rw unidirectional-packet-loss? decimal64
 | +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw normality
 | +--rw unidirectional-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-min-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-max-delay?
te-types:performance-metric-normality
 | +--rw unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--rw unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--rw unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--rw unidirectional-available-bandwidth?

```

```

te-types:performance-metric-normality
| +--rw unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 +--rw throttle
 +--rw unidirectional-delay-offset? uint32
 +--rw measure-interval? uint32
 +--rw advertisement-interval? uint32
 +--rw suppression-interval? uint32
 +--rw threshold-out
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
| +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
| +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-in
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
| +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
| +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw threshold-accelerated-advertisement
 +--rw unidirectional-delay? uint32
 +--rw unidirectional-min-delay? uint32
 +--rw unidirectional-max-delay? uint32
 +--rw unidirectional-delay-variation? uint32
 +--rw unidirectional-packet-loss? decimal64
 +--rw unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--rw unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/nd:network/lnk:link/tet:te
/tet:information-source-entry:
 +--ro performance-metric
 +--ro measurement

```

```

 | +--ro unidirectional-delay? uint32
 | +--ro unidirectional-min-delay? uint32
 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro normality
 | +--ro unidirectional-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-min-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-max-delay?
te-types:performance-metric-normality
 | +--ro unidirectional-delay-variation?
te-types:performance-metric-normality
 | +--ro unidirectional-packet-loss?
te-types:performance-metric-normality
 | +--ro unidirectional-residual-bandwidth?
te-types:performance-metric-normality
 | +--ro unidirectional-available-bandwidth?
te-types:performance-metric-normality
 | +--ro unidirectional-utilized-bandwidth?
te-types:performance-metric-normality
 | +--ro throttle
 | +--ro unidirectional-delay-offset? uint32
 | +--ro measure-interval? uint32
 | +--ro advertisement-interval? uint32
 | +--ro suppression-interval? uint32
 | +--ro threshold-out
 | | +--ro unidirectional-delay? uint32
 | | +--ro unidirectional-min-delay? uint32
 | | +--ro unidirectional-max-delay? uint32
 | | +--ro unidirectional-delay-variation? uint32
 | | +--ro unidirectional-packet-loss? decimal64
 | | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro threshold-in
 | | +--ro unidirectional-delay? uint32
 | | +--ro unidirectional-min-delay? uint32

```

```

 | +--ro unidirectional-max-delay? uint32
 | +--ro unidirectional-delay-variation? uint32
 | +--ro unidirectional-packet-loss? decimal64
 | +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 | +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro threshold-accelerated-advertisement
 +--ro unidirectional-delay? uint32
 +--ro unidirectional-min-delay? uint32
 +--ro unidirectional-max-delay? uint32
 +--ro unidirectional-delay-variation? uint32
 +--ro unidirectional-packet-loss? decimal64
 +--ro unidirectional-residual-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-available-bandwidth?
rt-types:bandwidth-ieee-float32
 +--ro unidirectional-utilized-bandwidth?
rt-types:bandwidth-ieee-float32
 augment /nd:networks/tet:te/tet:templates/tet:link-template
/tet:te-link-attributes/tet:interface-switching-capability:
 +--rw packet-switch-capable
 +--rw minimum-lsp-bandwidth? rt-types:bandwidth-ieee-float32
 +--rw interface-mtu? uint16
 augment /nd:networks/nd:network/lnk:link/tet:te
/tet:te-link-attributes/tet:interface-switching-capability:
 +--rw packet-switch-capable
 +--rw minimum-lsp-bandwidth? rt-types:bandwidth-ieee-float32
 +--rw interface-mtu? uint16
 augment /nd:networks/nd:network/lnk:link/tet:te
/tet:information-source-entry/tet:interface-switching-capability:
 +--ro packet-switch-capable
 +--ro minimum-lsp-bandwidth? rt-types:bandwidth-ieee-float32
 +--ro interface-mtu? uint16

```

#### 4. YANG Modules

##### 4.1. Layer 3 TE Topology Module

```

<CODE BEGINS> file "ietf-l3-te-topology@2017-07-03.yang"
module ietf-l3-te-topology {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-l3-te-topology";
 prefix "l3tet";

```

```
import ietf-network {
 prefix "nd";
}
import ietf-network-topology {
 prefix "lnk";
}
import ietf-l3-unicast-topology {
 prefix "l3t";
}
import ietf-te-topology {
 prefix "tet";
}

organization "TBD";
contact "TBD";
description "L3 TE Topology model";

revision 2017-07-03 {

 description "Initial revision";
 reference "TBD";
}

grouping l3-te-topology-type {
 description
 "Identifies the L3 TE topology type.";
 container l3-te {
 presence "indiates L3 TE Topology";
 description
 "Its presence identifies the L3 TE topology type.";
 }
}

augment "/nd:networks/nd:network/nd:network-types/"
+ "l3t:l3-unicast-topology" {
 description
 "Defines the L3 TE topology type.";
 uses l3-te-topology-type;
}

augment "/nd:networks/nd:network/l3t:l3-topology-attributes" {
 when "../nd:network-types/l3t:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment topology configuration";
 uses l3-te-topology-attributes;
}
```

```
augment "/nd:networks/nd:network/nd:node/l3t:l3-node-attributes" {
 when "../..//nd:network-types/l3t:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment node configuration";
 uses l3-te-node-attributes;
}

augment "/nd:networks/nd:network/nd:node/l3t:l3-termination-point/"
+ "l3t:l3-termination-point-attributes" {
 when "../..//nd:network-types/l3t:l3-unicast-topology/"
+ "l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment termination point configuration";
 uses l3-te-tp-attributes;
}

augment "/nd:networks/nd:network/l3t:l3-link-attributes" {
 when "../..//nd:network-types/l3t:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment link configuration";
 uses l3-te-link-attributes;
}

grouping l3-te-topology-attributes {
 description "L3 TE topology scope attributes";
 container l3-te-topology-attributes {
 must "/nd:networks/nd:network"
 + "[nd:network-id = current()/network-ref]/nd:network-types/"
 + "tet:te-topology" {
 error-message
 "The referenced network must be a TE topology.";
 description
 "The referenced network must be a TE topology.";
 }
 description "Containing TE topology references";
 uses nd:network-ref;
 } // l3-te-topology-attributes
} // l3-te-topology-attributes

grouping l3-te-node-attributes {
 description "L3 TE node scope attributes";
 container l3-te-node-attributes {
 must "/nd:networks/nd:network"
 + "[nd:network-id = current()/network-ref]/nd:network-types/"
 + "tet:te-topology" {
```

```
 error-message
 "The referenced network must be a TE topology.";
 description
 "The referenced network must be a TE topology.";
 }
 description "Containing TE node references";
 uses nd:node-ref;
 } // l3-te
 } // l3-te-node-attributes

grouping l3-te-tp-attributes {
 description "L3 TE termination point scope attributes";
 container l3-te-tp-attributes {
 must "/nd:networks/nd:network"
 + "[nd:network-id = current()/network-ref]/nd:network-types/"
 + "tet:te-topology" {
 error-message
 "The referenced network must be a TE topology.";
 description
 "The referenced network must be a TE topology.";
 }
 description "Containing TE termination point references";
 uses lnk:tp-ref;
 } // l3-te
} // l3-te-tp-attributes

grouping l3-te-link-attributes {
 description "L3 TE link scope attributes";
 container l3-te-link-attributes {
 must "/nd:networks/nd:network"
 + "[nd:network-id = current()/network-ref]/nd:network-types/"
 + "tet:te-topology" {
 error-message
 "The referenced network must be a TE topology.";
 description
 "The referenced network must be a TE topology.";
 }
 description "Containing TE link references";
 uses lnk:link-ref;
 }
} // l3-te-link-attributes
}
<CODE ENDS>
```

## 4.2. Packet Switching TE Topology Module

```
<CODE BEGINS> file "ietf-te-topology-packet@2017-10-29.yang"
module ietf-te-topology-packet {
 yang-version 1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-te-topology-packet";

 prefix "tet-pkt";

 import ietf-network {
 prefix "nd";
 }

 import ietf-network-topology {
 prefix "lnk";
 }

 import ietf-routing-types {
 prefix "rt-types";
 }

 import ietf-te-topology {
 prefix "tet";
 }

 import ietf-te-types {
 prefix "te-types";
 }

 organization
 "Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

 contact
 "WG Web: <http://tools.ietf.org/wg/teas/>
 WG List: <mailto:teas@ietf.org>

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 <mailto:lberger@labn.net>

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Himanshu Shah  
<mailto:hshah@ciena.com>

Oscar Gonzalez De Dios  
<mailto:oscar.gonzalezdedios@telefonica.com>;

```
description "TE topology model";

revision 2017-10-29 {
 description "Initial revision";
 reference "TBD";
}

/*
 * Features
 */

feature te-performance-metric {
 description
 "This feature indicates that the system supports
 TE performance metric.";
 reference
 "RFC7471: OSPF Traffic Engineering (TE) Metric Extensions.
 RFC7810: IS-IS Traffic Engineering (TE) Metric Extensions.
 RFC7823: Performance-Based Path Selection for Explicitly
 Routed Label Switched Paths (LSPs) Using TE Metric
 Extensions";
}

/*
 * Groupings
 */
grouping packet-switch-capable-container {
 description
 "The container of packet switch capable attributes.";
 container packet-switch-capable {
 description
 "Interface has packet-switching capabilities.";
 leaf minimum-lsp-bandwidth {
 type rt-types:bandwidth-ieee-float32;
 }
 }
}
```

```
 description
 "Minimum LSP Bandwidth. Units in bytes per second";
 }
 leaf interface-mtu {
 type uint16;
 description
 "Interface MTU.";
 }
}

/*
 * Augmentations
 */
/* Augmentations to connectivity-matrix */
augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:te-node-attributes/tet:connectivity-matrices" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:te-node-attributes/tet:connectivity-matrices/"
 + "tet:connectivity-matrix" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:information-source-entry/tet:connectivity-matrices" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:information-source-entry/tet:connectivity-matrices/"
 + "tet:connectivity-matrix" {
```

```
description
 "Parameters for PSC TE topology.";
uses te-types:performance-metric-container {
 if-feature te-performance-metric;
}

/* Augmentations to tunnel-termination-point */
augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:tunnel-termination-point/"
 + "tet:local-link-connectivities" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

augment "/nd:networks/nd:network/nd:node/tet:te/"
 + "tet:tunnel-termination-point/"
 + "tet:local-link-connectivities/"
 + "tet:local-link-connectivity" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

/* Augmentations to te-link-attributes */
augment "/nd:networks/tet:te/tet:templates/"
 + "tet:link-template/tet:te-link-attributes" {
 when "tet:interface-switching-capability "
 + "[tet:switching-capability = 'te-types:switching-psc1']" {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
}

augment "/nd:networks/nd:network/lnk:link/tet:te/"
 + "tet:te-link-attributes" {
 when "tet:interface-switching-capability "
 + "[tet:switching-capability = 'te-types:switching-psc1']" {
 description "Valid only for PSC";
 }
}
```

```

 }
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
 }

augment "/nd:networks/nd:network/lnk:link/tet:te/"
 + "tet:information-source-entry" {
 when "tet:interface-switching-capability "
 + "[tet:switching-capability = 'te-types:switching-psc1']" {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature te-performance-metric;
 }
 }

/* Augmentations to interface-switching-capability */
augment "/nd:networks/tet:te/tet:templates/"
 + "tet:link-template/tet:te-link-attributes/"
 + "tet:interface-switching-capability" {
 when "tet:switching-capability = 'te-types:switching-psc1' " {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses packet-switch-capable-container;
 }

augment "/nd:networks/nd:network/lnk:link/tet:te/"
 + "tet:te-link-attributes/"
 + "tet:interface-switching-capability" {
 when "tet:switching-capability = 'te-types:switching-psc1' " {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses packet-switch-capable-container;
 }

augment "/nd:networks/nd:network/lnk:link/tet:te/"
 + "tet:information-source-entry/"
 + "tet:interface-switching-capability" {
 when "tet:switching-capability = 'te-types:switching-psc1' " {

```

```
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses packet-switch-capable-container;
}
}
<CODE ENDS>
```

## 5. IANA Considerations

RFC Ed.: In this section, replace all occurrences of 'XXXX' with the actual RFC number (and remove this note).

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```

URI: urn:ietf:params:xml:ns:yang:ietf-l3-te-topology
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-l3-te-topology-state
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-te-topology-packet
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-te-topology-packet-state
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

This document registers the following YANG modules in the YANG Module Names registry [RFC6020]:

```

name: ietf-l3-te-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-l3-te-topology
prefix: l3te
reference: RFC XXXX

```

```

name: ietf-l3-te-topology-state
namespace: urn:ietf:params:xml:ns:yang:ietf-l3-te-topology-state
prefix: l3te-s
reference: RFC XXXX

```

```

name: ietf-te-topology-packet
namespace: urn:ietf:params:xml:ns:yang:ietf-te-topology-packet
prefix: tet-pkt
reference: RFC XXXX

```

```

name: ietf-te-topology-packet-state
namespace: urn:ietf:params:xml:ns:yang:ietf-te-topology-packet-state
prefix: tet-pkt-s
reference: RFC XXXX

```

## 6. Security Considerations

The configuration, state, action and notification data defined in this document are designed to be accessed via the NETCONF protocol [RFC6241]. The data-model by itself does not create any security implications. The security considerations for the NETCONF protocol are applicable. The NETCONF protocol used for sending the data supports authentication and encryption.

## 7. References

### 7.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.

[RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <<https://www.rfc-editor.org/info/rfc7950>>.

[I-D.ietf-netmod-revised-datastores]  
Bjorklund, M., Schoenwaelder, J., Shafer, P., Watsen, K., and R. Wilton, "Network Management Datastore Architecture", draft-ietf-netmod-revised-datastores-05 (work in progress), October 2017.

## 7.2. Informative References

[I-D.ietf-i2rs-yang-l3-topology]  
Clemm, A., Medved, J., Varga, R., Liu, X., Ananthakrishnan, H., and N. Bahadur, "A YANG Data Model for Layer 3 Topologies", draft-ietf-i2rs-yang-l3-topology-12 (work in progress), October 2017.

[I-D.ietf-teas-yang-te-topo]  
Liu, X., Bryskin, I., Beeram, V., Saad, T., Shah, H., and O. Dios, "YANG Data Model for TE Topologies", draft-ietf-teas-yang-te-topo-12 (work in progress), July 2017.

## Appendix A. Companion YANG Model for Non-NMDA Compliant Implementations

The YANG modules `ietf-l3-te-topology` and `ietf-te-topology-packet` defined in this document are designed to be used in conjunction with implementations that support the Network Management Datastore Architecture (NMDA) defined in [I-D.ietf-netmod-revised-datastores]. In order to allow implementations to use the model even in cases when NMDA is not supported, the following companion modules, `ietf-l3-te-topology-state` and `ietf-te-topology-packet-state`, are defined as state models, which mirror the modules `ietf-l3-te-topology` and `ietf-te-topology-packet` defined earlier in this document. However, all data nodes in the companion module are non-configurable, to represent the applied configuration or the derived operational states.

The companion modules, `ietf-l3-te-topology-state` and `ietf-te-topology-packet-state`, are redundant and SHOULD NOT be supported by implementations that support NMDA.

As the structure of the companion modules mirrors that of the cooresponding NMDA models, the YANG trees of the companion modules are not depicted separately.

## A.1. Layer 3 TE Topology State Module

```
<CODE BEGINS> file "ietf-l3-te-topology-state@2017-07-03.yang"
module ietf-l3-te-topology-state {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-l3-te-topology-state";
 prefix "l3tet-s";

 import ietf-l3-te-topology {
 prefix "l3tet";
 }
 import ietf-network-state {
 prefix "nd-s";
 }
 import ietf-network-topology-state {
 prefix "lnk-s";
 }
 import ietf-l3-unicast-topology-state {
 prefix "l3t-s";
 }

 organization "TBD";
 contact "TBD";
 description "L3 TE Topology model";
}
```



```
revision 2017-07-03 {
 description "Initial revision";
 reference "TBD";
}

augment "/nd-s:networks/nd-s:network/nd-s:network-types/"
+ "l3t-s:l3-unicast-topology" {
 description
 "Defines the L3 TE topology type.";
 uses l3tet:l3-te-topology-type;
}

augment "/nd-s:networks/nd-s:network/"
+ "l3t-s:l3-topology-attributes" {
 when "../nd-s:network-types/l3t-s:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment topology configuration";
 uses l3tet:l3-te-topology-attributes;
}

augment "/nd-s:networks/nd-s:network/nd-s:node/"
+ "l3t-s:l3-node-attributes" {
 when "../..../nd-s:network-types/l3t-s:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment node configuration";
 uses l3tet:l3-te-node-attributes;
}

augment "/nd-s:networks/nd-s:network/nd-s:node/"
+ "lnk-s:termination-point/"
+ "l3t-s:l3-termination-point-attributes" {
 when "../..../nd-s:network-types/l3t-s:l3-unicast-topology/"
 + "l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment termination point configuration";
 uses l3tet:l3-te-tp-attributes;
}

augment "/nd-s:networks/nd-s:network/lnk-s:link/"
+ "l3t-s:l3-link-attributes" {
 when "../..../nd-s:network-types/l3t-s:l3-unicast-topology/l3-te" {
 description "Augment only for L3 TE topology";
 }
 description "Augment link configuration";
}
```

```
 uses l3tet:l3-te-link-attributes;
 }
}
<CODE ENDS>
```

## A.2. Packet Switching TE Topology State Module

```
<CODE BEGINS> file "ietf-te-topology-packet-state@2017-10-29.yang"
module ietf-te-topology-packet-state {
 yang-version 1;
 namespace
 "urn:ietf:params:xml:ns:yang:ietf-te-topology-packet-state";

 prefix "tet-pkt-s";

 import ietf-te-topology-packet {
 prefix "tet-pkt";
 }

 import ietf-network-state {
 prefix "nd-s";
 }

 import ietf-network-topology-state {
 prefix "lnk-s";
 }

 import ietf-te-topology-state {
 prefix "tet-s";
 }

 import ietf-te-types {
 prefix "te-types";
 }

 organization
 "Traffic Engineering Architecture and Signaling (TEAS)
 Working Group";

 contact
 "WG Web: <http://tools.ietf.org/wg/teas/>
 WG List: <mailto:teas@ietf.org>

 WG Chair: Lou Berger
 <mailto:lberger@labn.net>
```

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Himanshu Shah  
<mailto:hshah@ciena.com>

Oscar Gonzalez De Dios  
<mailto:oscar.gonzalezdedios@telefonica.com>;

```
description "TE topology model";

revision 2017-10-29 {
 description "Initial revision";
 reference "TBD";
}

/*
 * Augmentations
 */
/* Augmentations to connectivity-matrix */
augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
+ "tet-s:te-node-attributes/tet-s:connectivity-matrices" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
}

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
+ "tet-s:te-node-attributes/tet-s:connectivity-matrices/"
+ "tet-s:connectivity-matrix" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
}
```

```

 }
 }

 augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
 + "tet-s:information-source-entry/"
 + "tet-s:connectivity-matrices" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
 }

 augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
 + "tet-s:information-source-entry/"
 + "tet-s:connectivity-matrices/"
 + "tet-s:connectivity-matrix" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
 }

 /* Augmentations to tunnel-termination-point */
 augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
 + "tet-s:tunnel-termination-point/"
 + "tet-s:local-link-connectivities" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
 }

 augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te/"
 + "tet-s:tunnel-termination-point/"
 + "tet-s:local-link-connectivities/"
 + "tet-s:local-link-connectivity" {
 description
 "Parameters for PSC TE topology.";
 uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
 }
 }

 /* Augmentations to te-link-attributes */
 augment "/nd-s:networks/tet-s:te/tet-s:templates/"

```

```

 + "tet-s:link-template/tet-s:te-link-attributes" {
when "tet-s:interface-switching-capability "
+ "[tet-s:switching-capability = 'te-types:switching-pscl']" {
 description "Valid only for PSC";
}
description
 "Parameters for PSC TE topology.";
uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
}
}

augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te/"
+ "tet-s:te-link-attributes" {
when "tet-s:interface-switching-capability "
+ "[tet-s:switching-capability = 'te-types:switching-pscl']" {
 description "Valid only for PSC";
}
description
 "Parameters for PSC TE topology.";
uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
}
}

augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te/"
+ "tet-s:information-source-entry" {
when "tet-s:interface-switching-capability "
+ "[tet-s:switching-capability = 'te-types:switching-pscl']" {
 description "Valid only for PSC";
}
description
 "Parameters for PSC TE topology.";
uses te-types:performance-metric-container {
 if-feature tet-pkt:te-performance-metric;
}
}

/* Augmentations to interface-switching-capability */
augment "/nd-s:networks/tet-s:te/tet-s:templates/"
+ "tet-s:link-template/tet-s:te-link-attributes/"
+ "tet-s:interface-switching-capability" {
when "tet-s:switching-capability = 'te-types:switching-pscl' " {
 description "Valid only for PSC";
}
description
 "Parameters for PSC TE topology.";
uses tet-pkt:packet-switch-capable-container;
}

```

```
 }

 augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te/"
 + "tet-s:te-link-attributes/"
 + "tet-s:interface-switching-capability" {
 when "tet-s:switching-capability = 'te-types:switching-psc1' " {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses tet-pkt:packet-switch-capable-container;
 }

 augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te/"
 + "tet-s:information-source-entry/"
 + "tet-s:interface-switching-capability" {
 when "tet-s:switching-capability = 'te-types:switching-psc1' " {
 description "Valid only for PSC";
 }
 description
 "Parameters for PSC TE topology.";
 uses tet-pkt:packet-switch-capable-container;
 }
 }
}<CODE ENDS>
```

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YANG Data Model for SR and SR TE Topologies  
draft-liu-teas-yang-sr-te-topo-04

Abstract

This document defines a YANG data model for Segment Routing (SR) topology and Segment Routing (SR) traffic engineering (TE) topology.

Status of This Memo

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## 1. Introduction

This document defines a YANG [RFC7950] data model for describing the presentations of Segment Routing (SR) topology and Segment Routing (SR) traffic engineering (TE) topology.

### 1.1. Terminology

The keywords "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14, [RFC2119].

The following terms are defined in [RFC7950] and are not redefined here:

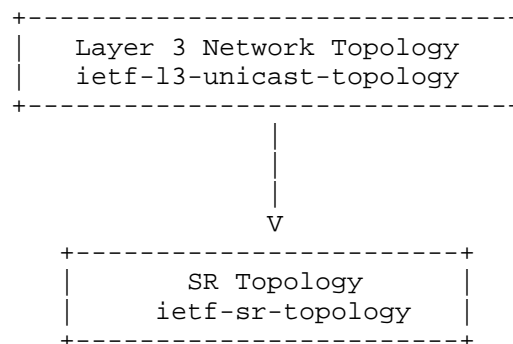
- o augment
- o data model

- o data node

## 2. Modeling Considerations

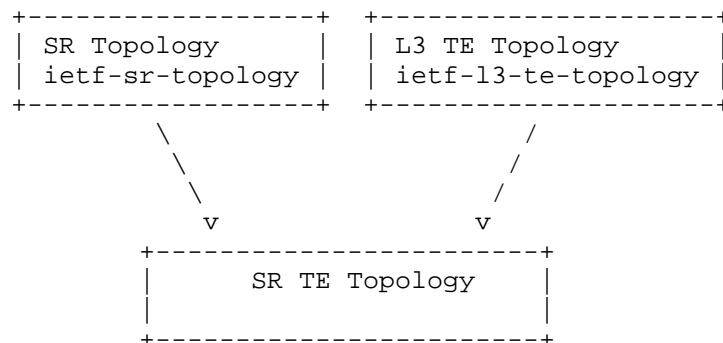
### 2.1. Segment Routing (SR) topology

The Layer 3 network topology model is discussed in [I-D.ietf-i2rs-yang-l3-topology]. The Segment Routing (SR) topology model proposed in this document augments and uses the ietf-l3-unicast-igp-topology module defined in [I-D.ietf-i2rs-yang-l3-topology]. SR related attributes are covered in the ietf-sr-topology model.



### 2.2. Segment Routing (SR) TE topology

When traffic engineering is enabled on an SR topology, there will be associations between objects in SR topologies and objects in TE topologies. An SR TE topology is both an SR topology and a layer 3 TE topology. Multiple inheritance is used to achieve such relations.



Each type of topologies is indicated by "network-types" defined in [I-D.ietf-i2rs-yang-network-topol]. For the three types of topologies above, the data representations are:

L3 Topology:

```
/nd:networks/nd:network/nd:network-types/l3-unicast-topology
```

L3 TE Topology:

```
/nd:networks/nd:network/nd:network-types/l3-unicast-topology/l3-te
```

SR Topology:

```
/nd:networks/nd:network/nd:network-types/l3-unicast-topology/sr
```

SR TE Topology: (multiple inheritance)

```
/nd:networks/nd:network/nd:network-types/l3-unicast-topology/l3-te
/nd:networks/nd:network/nd:network-types/l3-unicast-topology/sr
```

### 2.3. Relations to ietf-segment-routing

[I-D.ietf-spring-sr-yang] defines ietf-segment-routing that is a model intended to be used on network elements to configure or operate segment routing; ietf-sr-topology defined in this document is intended to be used on a controller for the network-wide operations such as path computation.

SR topology model shares many modeling constructs defined in ietf-segment-routing. The module ietf-sr-topology uses the types and groupings defined in ietf-segment-routing.

### 2.4. Open Items

- a. Protection on link: The feature of link protection will be modeled in the next revision.
- b. Link bundle: The feature of link bundle will be modeled in the next revision.

## 3. Model Structure

The model tree structure of the Segment Routing (SR) topology module is as shown below:

```

module: ietf-sr-topology
 augment /nw:networks/nw:network/nw:network-types
 /l3t:l3-unicast-topology:
 +--rw sr!
 augment /nw:networks/nw:network/l3t:l3-topology-attributes:
 +--rw sr
 +--rw srgb* [lower-bound upper-bound]
 +--rw lower-bound uint32
 +--rw upper-bound uint32
 augment /nw:networks/nw:network/nw:node/l3t:l3-node-attributes:
 +--rw sr
 +--rw srgb* [lower-bound upper-bound]
 | +--rw lower-bound uint32
 | +--rw upper-bound uint32
 +--rw srlb* [lower-bound upper-bound]
 | +--rw lower-bound uint32
 | +--rw upper-bound uint32
 +--rw node-capabilities
 | +--rw transport-planes* [transport-plane]
 | | +--rw transport-plane identityref
 | +--rw readable-label-stack-depth? uint8
 +--ro information-source? enumeration
 +--ro information-source-state
 +--ro credibility-preference? uint16
 augment /nw:networks/nw:network/nw:node/l3t:l3-node-attributes
 /l3t:prefix:
 +--rw sr!
 +--rw value-type? enumeration
 +--rw start-sid uint32
 +--rw range? uint32
 +--rw algorithm? identityref
 +--rw last-hop-behavior? enumeration
 {sid-last-hop-behavior}?
 +--rw is-local? boolean
 augment /nw:networks/nw:network/nw:node/nt:termination-point
 /l3t:l3-termination-point-attributes:
 augment /nw:networks/nw:network/nt:link/l3t:l3-link-attributes:
 +--rw sr
 +--rw sid? uint32
 +--rw value-type? enumeration
 +--rw is-local? boolean
 +--ro is-part-of-set? boolean
 +--ro is-on-lan? boolean
 +--ro information-source? enumeration
 +--ro information-source-state
 +--ro credibility-preference? uint16

```

## 4. YANG Module

```
<CODE BEGINS> file "ietf-sr-topology@2017-10-30.yang"
module ietf-sr-topology {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-sr-topology";
 prefix "srt";

 import ietf-network {
 prefix "nw";
 }
 import ietf-network-topology {
 prefix "nt";
 }
 import ietf-l3-unicast-topology {
 prefix "l3t";
 }
 import ietf-segment-routing-common {
 prefix "sr-cmn";
 }

 organization "TBD";
 contact "TBD";
 description "L3 TE Topology model";

 revision 2017-10-30 {
 description "Initial revision";
 reference "TBD";
 }

 grouping sr-topology-type {
 description
 "Identifies the SR topology type.";
 container sr {
 presence "Indiates SR Topology";
 description
 "Its presence identifies the SR topology type.";
 }
 }

 augment "/nw:networks/nw:network/nw:network-types/"
 + "l3t:l3-unicast-topology" {
 description
 "Defines the SR topology type.";
 uses sr-topology-type;
 }
}
```

```
augment "/nw:networks/nw:network/l3t:l3-topology-attributes" {
 when "../nw:network-types/l3t:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment topology configuration";
 uses sr-topology-attributes;
}

augment "/nw:networks/nw:network/nw:node/l3t:l3-node-attributes" {
 when "../nw:network-types/l3t:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment node configuration.";
 uses sr-node-attributes;
}

augment "/nw:networks/nw:network/nw:node/l3t:l3-node-attributes"
+ "/l3t:prefix" {
 when "../nw:network-types/l3t:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment node prefix.";
 uses sr-node-prefix-attributes;
}

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
+ "l3t:l3-termination-point-attributes" {
 when "../nw:network-types/l3t:l3-unicast-topology/"
+ "sr" {
 description "Augment only for SR topology.";
 }
 description "Augment termination point configuration";
 uses sr-tp-attributes;
}

augment "/nw:networks/nw:network/nt:link/l3t:l3-link-attributes" {
 when "../nw:network-types/l3t:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment link configuration.";
 uses sr-link-attributes;
}

grouping sr-topology-attributes {
 description "SR topology scope attributes.";
 container sr {
 description
 "Containing SR attributes.";
 }
}
```

```
 uses sr-cmn:srgb-cfg;
 } // sr
} // sr-topology-attributes

grouping information-source-attributes {
 description
 "The attributes identifying source that has provided the
 related information, and the source credibility.";
 leaf information-source {
 type enumeration {
 enum "unknown" {
 description "The source is unknown.";
 }
 enum "locally-configured" {
 description "Configured entity.";
 }
 enum "ospfv2" {
 description "OSPFv2.";
 }
 enum "ospfv3" {
 description "OSPFv3.";
 }
 enum "isis" {
 description "ISIS.";
 }
 enum "system-processed" {
 description "System processed entity.";
 }
 enum "other" {
 description "Other source.";
 }
 }
 }
 config false;
 description
 "Indicates the source of the information.";
}
container information-source-state {
 config false;
 description
 "The container contains state attributes related to
 the information source.";
 leaf credibility-preference {
 type uint16;
 description
 "The preference value to calculate the traffic
 engineering database credibility value used for
 tie-break selection between different
 information-source values.
```

```
 Higher value is more preferable.";
 }
}
} // information-source-attributes

grouping sr-node-attributes {
 description "SR node scope attributes.";
 container sr {
 description
 "Containing SR attributes.";
 uses sr-cmn:srgb-cfg;
 uses sr-cmn:srlb-cfg;
 uses sr-cmn:node-capabilities;
 // Operational state data
 uses information-source-attributes;
 } // sr
} // sr-node-attributes

grouping sr-node-prefix-attributes {
 description "Containing SR attributes for a prefix.";
 container sr {
 presence "Presence indicates SR is enabled.";
 description
 "Containing SR attributes for a prefix.";
 uses sr-cmn:prefix-sid-attributes;
 uses sr-cmn:last-hop-behavior;
 leaf is-local {
 type boolean;
 description
 "'true' if the SID is local.";
 }
 } // sr
} // sr-node-prefix-attributes

grouping sr-tp-attributes {
 description "SR termination point scope attributes";
} // sr-tp-attributes

grouping sr-link-attributes {
 description "SR link scope attributes";
 container sr {
 description
 "Containing SR attributes.";
 leaf sid {
 type uint32;
 description
 "SID.";
 }
 }
}
```



```
 uses sr-cmn:sid-value-type;
 leaf is-local {
 type boolean;
 description
 "'true' if the SID is local.";
 }
 leaf is-part-of-set {
 type boolean;
 config false;
 description
 "'true' if the SID is part of a set.";
 }
 leaf is-on-lan {
 type boolean;
 config false;
 description
 "'true' if on a lan.";
 }
 uses information-source-attributes;
} // sr
} // sr-link-attributes
}
<CODE ENDS>
```

## 5. IANA Considerations

RFC Ed.: In this section, replace all occurrences of 'XXXX' with the actual RFC number (and remove this note).

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```

URI: urn:ietf:params:xml:ns:yang:ietf-sr-topology
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

```

URI: urn:ietf:params:xml:ns:yang:ietf-sr-topology-state
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.

```

This document registers the following YANG modules in the YANG Module Names registry [RFC6020]:

```

name: ietf-sr-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-sr-topology
prefix: srt
reference: RFC XXXX

```

```

name: ietf-sr-topology-state
namespace: urn:ietf:params:xml:ns:yang:ietf-sr-topology-state
prefix: srt-s
reference: RFC XXXX

```

## 6. Security Considerations

The configuration, state, action and notification data defined in this document are designed to be accessed via the NETCONF protocol [RFC6241]. The data-model by itself does not create any security implications. The security considerations for the NETCONF protocol are applicable. The NETCONF protocol used for sending the data supports authentication and encryption.

## 7. References

### 7.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC6241] Enns, R., Ed., Bjorklund, M., Ed., Schoenwaelder, J., Ed., and A. Bierman, Ed., "Network Configuration Protocol (NETCONF)", RFC 6241, DOI 10.17487/RFC6241, June 2011, <<https://www.rfc-editor.org/info/rfc6241>>.
- [RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <<https://www.rfc-editor.org/info/rfc7950>>.
- [I-D.ietf-netmod-revised-datastores] Bjorklund, M., Schoenwaelder, J., Shafer, P., Watsen, K., and R. Wilton, "Network Management Datastore Architecture", draft-ietf-netmod-revised-datastores-05 (work in progress), October 2017.

## 7.2. Informative References

- [I-D.ietf-i2rs-yang-network-topo]  
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for Layer 3 Topologies", draft-ietf-i2rs-yang-  
l3-topology-12 (work in progress), October 2017.
- [I-D.ietf-teas-yang-te-topo]  
Liu, X., Bryskin, I., Beeram, V., Saad, T., Shah, H., and  
O. Dios, "YANG Data Model for TE Topologies", draft-ietf-  
teas-yang-te-topo-12 (work in progress), July 2017.
- [I-D.ietf-spring-sr-yang]  
Litkowski, S., Qu, Y., Sarkar, P., and J. Tantsura, "YANG  
Data Model for Segment Routing", draft-ietf-spring-sr-  
yang-07 (work in progress), July 2017.

## Appendix A. Companion YANG Model for Non-NMDA Compliant Implementations

The YANG module `ietf-sr-topology` defined in this document is designed to be used in conjunction with implementations that support the Network Management Datastore Architecture (NMDA) defined in [I-D.ietf-netmod-revised-datastores]. In order to allow implementations to use the model even in cases when NMDA is not supported, the following companion module, `ietf-sr-topology-state`, is defined as state model, which mirrors the module `ietf-sr-topology` defined earlier in this document. However, all data nodes in the companion module are non-configurable, to represent the applied configuration or the derived operational states.

The companion module, `ietf-sr-topology-state`, is redundant and SHOULD NOT be supported by implementations that support NMDA.

As the structure of the companion module mirrors that of the cooresponding NMDA model, the YANG tree of the companion module is not depicted separately.

## A.1. SR Topology State Module

```
<CODE BEGINS> file "ietf-sr-topology-state@2017-10-30.yang"
module ietf-sr-topology-state {
 yang-version 1.1;
 namespace "urn:ietf:params:xml:ns:yang:ietf-sr-topology-state";
 prefix "srt-s";

 import ietf-sr-topology {
 prefix "srt";
 }
 import ietf-network-state {
 prefix "nw-s";
 }
 import ietf-network-topology-state {
 prefix "nt-s";
 }
 import ietf-l3-unicast-topology-state {
 prefix "l3t-s";
 }
 import ietf-segment-routing-common {
 prefix "sr-cmn";
 }

 organization "TBD";
 contact "TBD";
 description "L3 TE Topology model";
```

```
revision 2017-10-30 {
 description "Initial revision";
 reference "TBD";
}

augment "/nw-s:networks/nw-s:network/nw-s:network-types/"
+ "l3t-s:l3-unicast-topology" {
 description
 "Defines the SR topology type.";
 uses srt:sr-topology-type;
}

augment "/nw-s:networks/nw-s:network/"
+ "l3t-s:l3-topology-attributes" {
 when "../nw-s:network-types/l3t-s:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment topology configuration";
 uses srt:sr-topology-attributes;
}

augment "/nw-s:networks/nw-s:network/nw-s:node/"
+ "l3t-s:l3-node-attributes" {
 when "../nw-s:network-types/l3t-s:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment node configuration.";
 uses srt:sr-node-attributes;
}

augment "/nw-s:networks/nw-s:network/nw-s:node/"
+ "l3t-s:l3-node-attributes/l3t-s:prefix" {
 when "../nw-s:network-types/l3t-s:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment node prefix.";
 uses srt:sr-node-prefix-attributes;
}

augment "/nw-s:networks/nw-s:network/nw-s:node/"
+ "nt-s:termination-point/"
+ "l3t-s:l3-termination-point-attributes" {
 when "../nw-s:network-types/l3t-s:l3-unicast-topology/"
+ "sr" {
 description "Augment only for SR topology.";
 }
 description "Augment termination point configuration";
 uses srt:sr-tp-attributes;
}
```

```
 }

 augment "/nw-s:networks/nw-s:network/nt-s:link/"
 + "l3t-s:l3-link-attributes" {
 when "../../../nw-s:network-types/l3t-s:l3-unicast-topology/sr" {
 description "Augment only for SR topology.";
 }
 description "Augment link configuration.";
 uses srt:sr-link-attributes;
 }

 grouping sr-topology-attributes {
 description "SR topology scope attributes.";
 container sr {
 description
 "Containing SR attributes.";
 uses sr-cmn:srgb-cfg;
 } // sr
 } // sr-topology-attributes
 }
<CODE ENDS>
```

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Extending YANG for events, actions, and finite state machine  
draft-sambo-opsawg-ccamp-supra-ext-yang-fsm-00

## Abstract

Network operators and service providers are facing the challenge of deployment of systems from different vendors while looking for a trade-off among transmission performance, network device reuse, and capital expenditure without the need of being tied to single vendor equipment. The deployment and operation of more dynamic and programmable transport optical network infrastructures can be driven by adopting model-driven and software-defined control and management paradigms. In this context, YANG enables to compile a set of consistent vendor-neutral data models for optical networks and components based on actual operational needs emerging from heterogeneous use cases. This document extends YANG from data to functional modeling in order to describe events, operations, and finite state machine of YANG-defined network elements. The proposed models can be applied in the context of optical networks to pre-instruct data plane devices (e.g., an optical transponder) on the actions to be performed (e.g., code adaptation) in case some events, such as physical layer degradations, occur.

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## 1. Introduction

Networks are evolving toward more programmability, flexibility, and multi-vendor interoperability. Multi-vendor interoperability can be applied in the context of nodes, i.e. a node composed of components provided by different vendors (named white box) is assembled under the same control system. This way, operators can optimize costs and network performance without the need of being tied to single vendor equipment. NETCONF protocol RFC6241 [RFC6241] based on YANG data modeling language RFC6020 [RFC6020] is emerging as a candidate Software Defined Networking (SDN) enabled protocol. First, NETCONF supports both control and management functionalities, thus permits high programmability. Then, YANG enables data modeling in a vendor-neutral way. Some recent works have provided YANG models to describe attributes of links (e.g., identification), nodes (e.g., connectivity matrix), media channels, and transponders (e.g., supported forward error correction - FEC) of networks

([I-D.ietf-i2rs-yang-network-topo] [I-D.vergara-ccamp-flexigrid-yang] [I-D.zhang-ccamp-ll-topo-yang]), also including optical technologies. Such draft mainly refers to elastic optical networks (EONs), i.e. optical networks based on flexible grid where circuits with different bandwidth requirements are switched. EONs are expected to employ flexible transponders, i.e. transponders supporting multiple bit rates, multiple modulation formats, and multiple codes. Such transponders permits the (re-) configuration of the bit rate value based on traffic requirements, as well as the configuration of the modulation format and code based on the physical characteristics of a path (e.g., quadrature phase shift keying is more robust than 16 quadrature amplitude modulation). This document extends YANG from data to functional modeling in order to describe events, operations, and finite state machine of YANG-defined network elements. Such models can be applied to a case of transponder reconfiguration in EONs. In particular, the model enables a centralized remote network controller (managed by a network operator) to instruct a transponder controller about the actions to perform when certain events (e.g., failures) occur. The actions to be taken and the events can be re-programmed on the device.

## 2. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC2119 [RFC2119].

### 3. Terminology

ABNO: Application-Based Network Operations

BER: Bit Error Rate

EON: Elastic Optical Network

FEC: Forward Error Correction

FSM: Finite State Machine

NETCONF: Network Configuration Protocol

OAM: Operation Administration and Maintenance

SDN: Software Defined Network

YANG: Yet Another Network Generator

### 4. Example of application

Flexible transponders enable several settings of transmission parameters' configuration, through the support of multiple modulation formats and forward error correction (FEC) schemes. This way, transmission parameters can be (re-)configured based on the physical layer conditions. The YANG model presented in this draft enables to pre-program reconfiguration settings of data plane devices in case of failures or physical layer degradations. In particular, soft failures are assumed. Soft failures imply transmission performance degradation, in turns a bit error rate (BER) increase, e.g. due to the ageing of some network devices. Without loosing generality, the ABNO architecture is assumed for the control and management of EONs (RFC7491 [RFC7491]). Considering the state of the art, when pre-FEC BER passes above a predefined threshold, it is expected that an alarm is sent to the OAM Handler, which communicates with the ABNO controller that may trigger an SDN controller (that could be the Provisioning Manager of ABNO RFC7491 [RFC7491]) for computing new transmission parameters. The involved ABNO modules are shown in the simplified ABNO architecture of Fig. 1. Then, transponders are reconfigured. When alarms related to several connections impacted by the soft failure are generated, this procedure may be particularly time consuming. The related workflow for transponder reconfiguration is shown in Fig. 2. The proposed model enables an SDN controller to instruct the transponder about reconfiguration of new transmission parameters values if a soft failure occurs. This can be done before the failure occurs (e.g., during the connection instantiation phase or during the connection service), so that data plane devices can

promptly reconfigure themselves without querying the SDN controller to trigger an on-demand recovery. This is expected to speed up the recovery process from soft failures. The related flow chart is shown in Fig. 3.

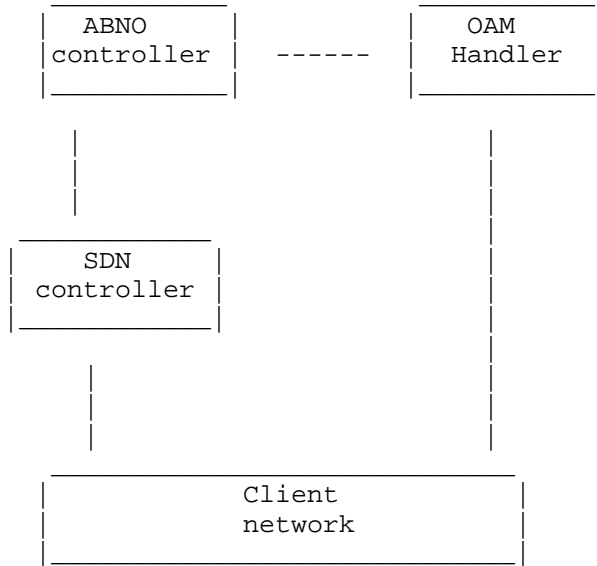


Figure 1: Assumed ABNO functional modules

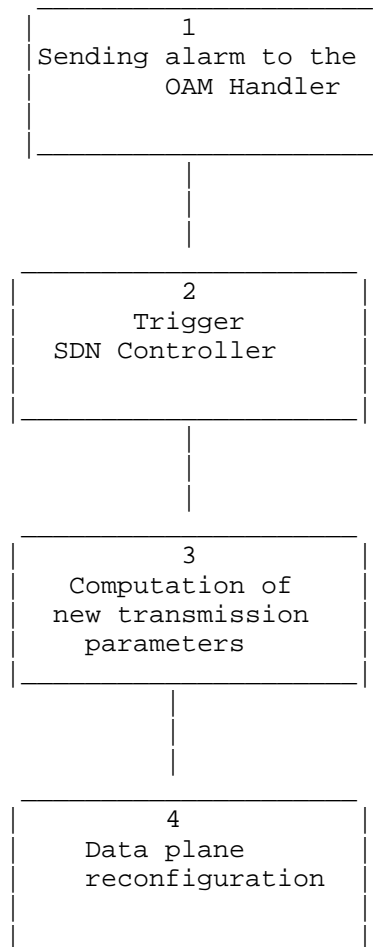


Figure 2: Flow chart of the expected state-of-the-art approach

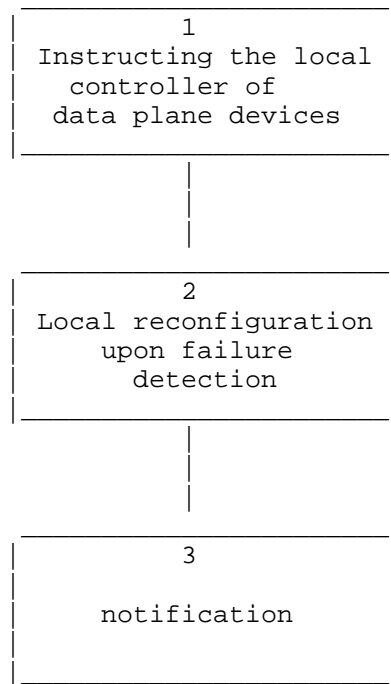


Figure 3: Flow chart of the approach exploiting YANG models in this draft

## 5. Extending YANG for events and reactions

The model extends YANG to define a list of events associated with specific reactions. The related code and tree are shown in the Appendix.

**<event>:** this element defines an event and it is composed by a set of leaves' attributes as follows.

- <name>:** this attribute defines the name of the event.
- <type>:** this attribute defines the type of the event from a pool of possible event types predefined inside the YANG model. Together with the **<name>** attribute, it uniquely identifies the event.
- <description>:** this optional attribute is a "string" describing the event
- <filters>:** this leaf is a list that enhances the description of an event. Given that an event does not necessary means a particular degradation or faults, this list can be used to define thresholds to express a measure

of the event.

- <filter>: this leaf of <filters> defines a threshold to characterize the event.
- <filter-id>: this leaf of <filters> define the identifier number associated with the <filter> attribute.

<reaction>: this attribute defines a list of operations to take if the event occurs.

- <operations>: this list defines the set of operations that have to be taken if the event occurs.
  - <id>: this leaf of <operations> defines the identifier number of an operation.
  - <type>: this leaf of <operations> defines the type of an operation.
  - <simple>: this leaf defines (differently from <conditional> detailed below) an operation that has to be directly executed.
    - <execute>: this attribute recalls an RPC encapsulating the effective task (operation) to be executed by the data plane hardware.
    - <next-operation>: this attribute defines the identification number of a next operation that has to be taken.
  - <conditional>: this leaf enables a check ("true" or "false") to be verified before executing the operation. Based on the check, the proper attributes <execute> and <next-operation> are considered.
    - <statement>: this leaf of <conditional> defines the condition to be verified before executing the operation.
  - <true>: this leaf of <conditional> defines a result of the check associated to <statement>. Proper <execute> and <next-operation> attributes are associated with this result of the check.
  - <false>: this leaf of <conditional> defines a result of the check associated to <statement>. Proper <execute> and <next-operation> attributes are

associated with this result of the check.

## 6. Extending YANG for finite state machine (FSM)

This model extends the one of the events and reactions by adding the state information and state transition. More precisely, the model defines a list of states associated with events. Each state has a description attribute and it is identified through an id. Each state includes a list of events as defined in the event model, with the additional next-state attribute, which points to the next state. The related code and tree are shown in the Appendix.

<current-state>: it defines the current state of the FSM.  
<states>: this element defines the FSM as follows.  
    <state>: this list defines all the FSM states.  
        <id>: this leaf attribute of <state> defines the identifier of the state  
        <name>: this leaf attribute of <state> defines the name of the state  
        <description>: this leaf is a "string" describing the state  
        <events>: this attribute is the one described in the previous section. In particular, this attribute defines a list of events that may induce a transition to another state in the FSM.  
            <next-state>: this attribute is included in the model <events> and defines the next state of FSM when an operation is executed.

## 7. Implementation for the considered use case of application

The models defined in this document are an extension of YANG through functions, events, and FSM, besides data modeling. These models can be used to enable a centralized network controller, managed by a network operator, to instruct data plane hardware on its reconfiguration if some events, such as a failure or physical layer degradation, occur. As an example, an optical signal impacted by a soft failure (i.e., a physical layer degradation inducing a pre forward error correction bit error rate increase - pre-FEC) can be maintained by adapting the FEC of the signal itself. This action to be taken and, more in general operations to be executed depending on critical events, can be (re-) programmed on the transponder by (re-) sending a NETCONF <edit-config> message to the device controller including a FSM defined by the YANG model. Such a system has the main goal to speed up the reaction of the network to certain events/



faults and to alleviate the workload of the centralized controller. The speed up derives from the fact that the centralized controller is able to pre-compute and pre-configure on the network devices the actions to take when an event occurs taking into account a global view and knowledge of the network. In this way, the device is already aware of the actions to be locally applied to reconfigure a connection, avoiding to inform the controller and to wait for the response indicating what to do. Consequently, part of the workload is also removed from the centralized controller. When the reaction is successfully completed in the data plane, the centralized controller can be notified about the faults and the taken action. A flexible transponder supporting two FEC types, 7% and 20%, is considered. A two-states FSM is also assumed. The states have <name> attribute set to "Steady" and "Fec-Baud-Adapt", respectively. In the "Steady" state, the signal is in a healthy condition, adopting a 7% FEC, with a pre-FEC BER below an assigned threshold of  $9 \times 10^{-4}$ . A transition from this state can be triggered by the event with <name>=BER\_CHANGE and <filter-type>= $9 \times 10^{-4}$ , thus expressing a change of the pre-FEC BER above the threshold. In case the pre-FEC BER exceeds  $9 \times 10^{-4}$  due to a soft failure, the state machine evolves to the "Fec-Baud-Adapt" state and an adaptation to a more robust FEC of 20% (executed by the attribute <execute>) is performed. The system can return to the "Steady" state if the pre-FEC BER goes below another pre-defined threshold and the FEC is reconfigured to 7%.

## 8. Appendix

This appendix reports the YANG models code and the related tree.

### 8.1. YANG model for events and actions - Tree

```
+--rw events
 +--rw event [name type]
 +--rw name string
 +--rw type event-type
 +--rw description? string
 +--rw filters
 | +--rw filter [filter-id]
 | +--rw filter-id yp:filter-id
 +--rw reaction
 +--rw operation [id]
 +--rw id event-id-type
 +--rw type enumeration
 +--rw conditional
 | +--rw statement string
 | +--rw true
 | | +--rw execute
 | | +--rw next-operation? event-id-type
 | +--rw false
 | +--rw execute
 | +--rw next-operation? event-id-type
 +--rw simple
 +--rw execute
 +--rw next-operation? event-id-type
```

## 8.2. YANG model for FSM - Tree

```

+--rw current-state? leafref
+--rw states
 +--rw state [id]
 +--rw id state-id-type
 +--rw name string
 +--rw description? string
 +--rw events
 +--rw event [name type]
 +--rw name string
 +--rw type event-type
 +--rw description? string
 +--rw filters
 +--rw filter [filter-id]
 +--rw filter-id yp:filter-id
 +--rw reaction
 +--rw operation [id]
 +--rw id event-id-type
 +--rw type enumeration
 +--rw conditional
 +--rw statement string
 +--rw true
 +--rw execute
 +--rw next-operation? event-id-type
 +--rw next-state? leafref
 +--rw false
 +--rw execute
 +--rw next-operation? event-id-type
 +--rw next-state? leafref
 +--rw simple
 +--rw execute
 +--rw next-operation? event-id-type
 +--rw next-state? leafref

```

### 8.3. YANG model for events and actions - Code

```

module events {
 namespace "http://sssup.it/events";
 prefix ev;

 import ietf-yang-push {
 prefix yp;
 }

 organization
 "Scuola Superiore Sant'Anna Network and Services Laboratory";

 contact
 " Editor: Matteo Dallaglio

```

```
 <mailto:m.dallaglio@sssup.it>
 ";

description
 "This module contains a YANG definitions of events and generic
 reactions.";

revision 2016-03-15 {
 description "Initial Revision.";
 reference
 "RFC xxxx: A YANG data model for the description of events and
 reactions";
}

// identity statements

identity EVENT {
 description "Base for all types of event";
}

identity ON_CHANGE {
 base EVENT;
 description
 "The event when the database changes.";
}

// typedef statements

typedef event-type {
 type identityref {
 base EVENT;
 }
}

typedef event-id-type {
 type uint32;
}

// grouping statements
grouping operation-block {
 leaf id {
 type event-id-type;
 }
 leaf type {
 type enumeration {
 enum CONDITIONAL_OP;
 enum SIMPLE_OP;
 }
 }
}
```

```
 }
 mandatory true;
 }

 grouping execution-top {
 anyxml execute {
 description "Represent the action to perform";
 }
 leaf next-operation {
 type event-id-type;
 description "the id of the next operation to execute";
 }
 }

 container conditional {
 when "../type = 'CONDITIONAL_OP'";
 leaf statement {
 type string;
 mandatory true;
 description
 "The statement to be evaluated before execution.
 E.g. if a=b";
 }
 container true {
 uses execution-top;
 }
 container false {
 uses execution-top;
 }
 }

 container simple {
 when "../type = 'SIMPLE_OP'";
 description
 "Simple execution of an action without checking any condition";
 uses execution-top;
 }
}

grouping operation-top {
 list operation {
 key "id";
 ordered-by user;
 uses operation-block;
 }
}

grouping on-change {
```

```
description
 "Event occurring when a modification of one or more
 objects occurs";

container filters {
 description
 "This container contains a list of configurable filters
 that can be applied to subscriptions. This facilitates
 the reuse of complex filters once defined.";
 list filter {
 key "filter-id";
 description
 "A list of configurable filters that can be applied to
 subscriptions.";
 leaf filter-id {
 type yp:filter-id;
 description
 "An identifier to differentiate between filters.";
 }
 uses yp:datatree-filter;
 }
}

grouping event-top {
 leaf name {
 type string;
 mandatory true;
 }

 leaf type {
 type event-type;
 mandatory true;
 }

 leaf description {
 type string;
 }

 // list of all possible events
 uses on-change {
 when "type = 'ON_CHANGE'";
 }

 container reaction {
 uses operation-top;
 }
}
```

```
grouping events-top {
 container events {
 list event {
 key "name type";
 uses event-top;
 }
 }
}

// data definition statements

uses events-top;

// extension statements

// feature statements

// augment statements

// rpc statements

// notification statements

} // module events
```

#### 8.4. YANG model for FSM - Code

```
module finite-state-machine {
 namespace "http://sssup.it/fsm";
 prefix fsm;

 import events {
 prefix ev;
 }

 organization
 "Scuola Superiore Sant'Anna Network and Services Laboratory";

 contact
 " Editor: Matteo Dallaglio
 <mailto:m.dallaglio@sssup.it>
 ";

 description
 "This module contains a YANG definitions of a generic finite state
```

```
machine.";

revision 2016-03-15 {
 description "Initial Revision.";
 reference
 "RFC xxxx:";
}

// identity statements

// typedef statements

typedef state-id-type {
 type uint32;
}

// grouping statements
grouping state-top {
 leaf id {
 type state-id-type;
 }

 leaf name {
 type string;
 }

 leaf description {
 type string;
 }

 grouping next-state-top {
 leaf next-state {
 type leafref {
 path "../.../../.../../.../../.../states/state/id";
 }
 description "Id of the next state";
 }
 }
}

uses ev:events-top {
 augment "events/event/reaction/operation/conditional/true" {
 uses next-state-top;
 }
 augment "events/event/reaction/operation/conditional/false" {
 uses next-state-top;
 }
}
```



```
augment "events/event/reaction/operation/simple" {
 //uses next-state-top;
 leaf next-state {
 type leafref {
 path "../.../../.../../.../../states/state/id";
 }
 description "Id of the next state";
 }
}
}
```

```
grouping states-top {
 leaf current-state {
 type leafref {
 path "../states/state/id";
 }
 }

 container states {
 list state {
 key "id";
 uses state-top;
 }
 }
}
```

```
// data definition statements
```

```
uses states-top;
```

```
// extension statements
```

```
// feature statements
```

```
// augment statements.
```

```
// rpc statements
```

```
// notification statements
```

```
}//module fsm
```

#### 8.5. Example of values for the YANG model

| FIELD NAME     | YANG DATA TYPE  | VALUE                                                  |
|----------------|-----------------|--------------------------------------------------------|
| Current State  | leafref         | "an existing state id in the FSM"                      |
| State          |                 |                                                        |
| id             | uint32          | 1                                                      |
| name           | string          | Steady                                                 |
| description    | string          | "whatever string"                                      |
| event          |                 |                                                        |
| name           | string          | "whatever string"                                      |
| type           | enum            | BER_CHANGE                                             |
| description    | string          | "whatever string"                                      |
| filter         |                 |                                                        |
| filter-id      | uint32          | 2                                                      |
| filter-type    | anyxml or xpath | BER>0.0009                                             |
| reaction       |                 |                                                        |
| id             | uint32          | 3                                                      |
| type           | enum            | SIMPLE                                                 |
| statement      | string          | "whatever string"                                      |
| execute        | anyxml          | "this recalls an RPC where the FEC value is expressed" |
| next-operation | uint32          | NULL                                                   |
| next-state     | leafref         | "an existing state id in the FSM"                      |

#### 9. Acknowledgements

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## 10. Security Considerations

TBD

## 11. References

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OTN Tunnel YANG Model  
draft-sharma-ccamp-otn-tunnel-model-02

Abstract

This document describes the YANG data model for OTN Tunnels.

Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

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## 1. Introduction

OTN transport networks can carry various types of client services. In many cases, the client signal is carried over an OTN tunnel across connected domains in a multi-domain network. These OTN services can either be transported or switched in the OTN network. If an OTN tunnel is switched, then additional parameters need to be provided to create a Mux OTN service.

This document provides YANG model for creating OTN tunnel. The model augments the TE Tunnel model, which is an abstract model to create TE Tunnels.

## 2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this draft is defined in [I-D.ietf-netmod-rfc6087bis]. They are provided below for reference.

- o Brackets "[" and "]" enclose list keys.
- o Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- o Symbols after data node names: "?" means an optional node, "!" means a presence container, and "\*" denotes a list and leaf-list.
- o Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- o Ellipsis ("...") stands for contents of subtrees that are not shown.

## 3. Model Overview

### 3.1. Mux Service in Multi-Domain OTN Network

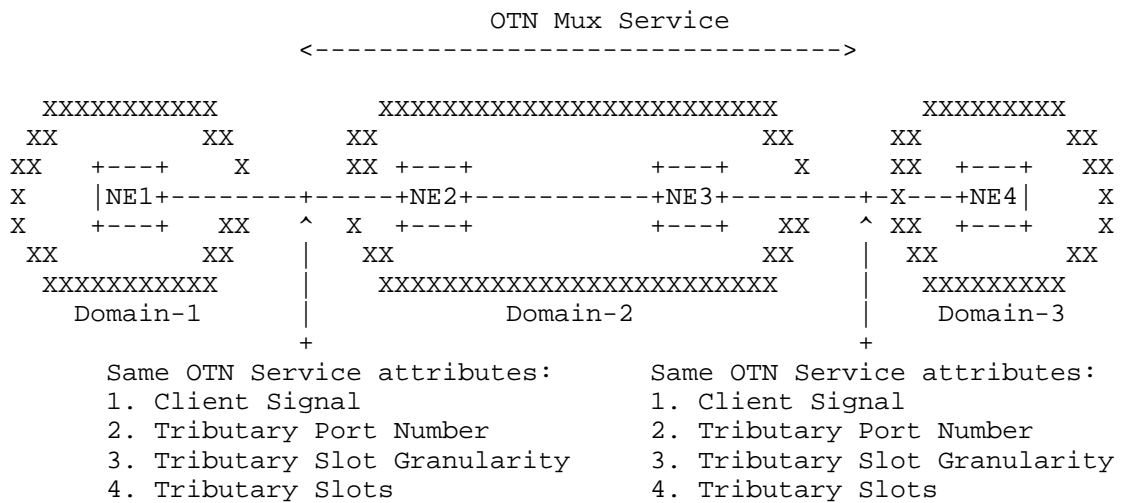


Figure 1: OTN Mux Service in a multi-domain network topology



Figure 1 shows a multi-domain OTN network with three domains. In this example, user wants to setup an end-to-end OTN service that passes through Domain-2. In order to create an OTN mux service in Domain-2, user will need to specify the exact details of the client side LO-ODU on NE2 and NE3, so that these service endpoints can be paired with the LO-ODU endpoints on NE1 and NE4, respectively.

Let's assume that ODU4 is the client side HO-ODU on NE2 and NE3, and the client signal is ODU2. User will need to specify the OTN client signal (ODU2 in this example), the Tributary Port Number (TPN), Tributary Slot Granularities (TSG) and tributary slots to be used. As shown in the figure above, these service parameters must be the same between NE1 and NE2, and NE3 and NE4.

Once the OTN Mux service is setup in Domain-2, the incoming signal from either NE1 and/or NE4 will be switched inside Domain-2, and delivered to NE at the other end.

### 3.2. Bookended and Non-BookEnded OTN Tunnel

OTN tunnel model provides support for both bookended and non-bookended OTN tunnels.

For bookended tunnels, the same client signal is present on source and destination endpoints. For example, ODU2e bookended tunnel will have the same ODU2e client signal at both source and destination endpoints.

For non-bookended tunnels, different client signals are present on source and destination endpoints. For example, the client signal can be ODU2e on the source endpoint and the handoff at the destination can be 10GbE-LAN client signal.

### 3.3. Network and Client side tunnel services

The OTN tunnel model provides support for both network to network and client to client tunnels. For network to network tunnel, network termination points on source and destination node represent source and destination endpoints. For client to client tunnel, client termination points on source and destination node represent source and destination endpoints.

If a client to client tunnel needs to use one or more HO (or server) network to network tunnels, ERO and routing constraints, defined in the base TE model, can be used to route the client tunnel over one or more server tunnels.

### 3.4. OTN Tunnel YANG Tree

```

module: ietf-otn-tunnel
augment /te:te/te:tunnels/te:tunnel/te:config:
 +--rw payload-treatment? enumeration
 +--rw src-client-signal? identityref
 +--rw src-tpn? uint16
 +--rw src-tsg? identityref
 +--rw src-tributary-slot-count? uint16
 +--rw src-tributary-slots
 | +--rw values* uint8
 +--rw dst-client-signal? identityref
 +--rw dst-tpn? uint16
 +--rw dst-tsg? identityref
 +--rw dst-tributary-slot-count? uint16
 +--rw dst-tributary-slots
 +--rw values* uint8
augment /te:te/te:tunnels/te:tunnel/te:state:
 +--ro payload-treatment? enumeration
 +--ro src-client-signal? identityref
 +--ro src-tpn? uint16
 +--ro src-tsg? identityref
 +--ro src-tributary-slot-count? uint16
 +--ro src-tributary-slots
 | +--ro values* uint8
 +--ro dst-client-signal? identityref
 +--ro dst-tpn? uint16
 +--ro dst-tsg? identityref
 +--ro dst-tributary-slot-count? uint16
 +--ro dst-tributary-slots
 +--ro values* uint8

```

### 3.5. OTN Tunnel YANG Code

```

<CODE BEGINS>file "ietf-otn-tunnel@2017-05-25.yang"

module ietf-otn-tunnel {
 yang-version 1.1;

 namespace "urn:ietf:params:xml:ns:yang:ietf-otn-tunnel";
 prefix "otn-tunnel";

 import ietf-te { prefix "te"; }
 import ietf-transport-types { prefix "tran-types"; }
 //import yang-ext { prefix ext; revision-date 2013-07-09; }

```

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description

"This module defines a model for OTN Tunnel Services.";

revision "2017-05-25" {

description

"Revision 0.3";

reference

"draft-sharma-ccamp-otn-tunnel-model-02.txt";

}

grouping otn-tunnel-endpoint {

description "Parameters for OTN tunnel.";

leaf payload-treatment {

type enumeration {

enum switching;

enum transport;

}

default switching;

description

```
 "Treatment of the incoming payload. Payload can
 either be switched, or transported as is.";
 }

 leaf src-client-signal {
 type identityref {
 base tran-types:client-signal;
 }
 description
 "Client signal at the source endpoint of
 the tunnel.";
 }

 leaf src-tpn {
 type uint16 {
 range "0..4095";
 }
 description
 "Tributary Port Number. Applicable in case of mux
 services.";
 reference
 "RFC7139: GMPLS Signaling Extensions for Control of
 Evolving G.709 Optical Transport Networks.";
 }

 leaf src-tsg {
 type identityref {
 base tran-types:tributary-slot-granularity;
 }
 description
 "Tributary slot granularity. Applicable in case of
 mux services.";
 reference
 "G.709/Y.1331, February 2016: Interfaces for the
 Optical Transport Network (OTN)";
 }

 leaf src-tributary-slot-count {
 type uint16;
 description
 "Number of tributary slots used at the source.";
 }

 container src-tributary-slots {
 description
 "A list of tributary slots used by the client
 service. Applicable in case of mux services.";
 leaf-list values {
```

```
 type uint8;
 description
 "Tributary tributary slot value.";
 reference
 "G.709/Y.1331, February 2016: Interfaces for the
 Optical Transport Network (OTN)";
 }
}

leaf dst-client-signal {
 type identityref {
 base tran-types:client-signal;
 }
 description
 "Client signal at the destination endpoint of
 the tunnel.";
}

leaf dst-tpn {
 type uint16 {
 range "0..4095";
 }
 description
 "Tributary Port Number. Applicable in case of mux
 services.";
 reference
 "RFC7139: GMPLS Signaling Extensions for Control of
 Evolving G.709 Optical Transport Networks.";
}

leaf dst-tsg {
 type identityref {
 base tran-types:tributary-slot-granularity;
 }
 description
 "Tributary slot granularity. Applicable in case of
 mux services.";
 reference
 "G.709/Y.1331, February 2016: Interfaces for the
 Optical Transport Network (OTN)";
}

leaf dst-tributary-slot-count {
 type uint16;
 description
 "Number of tributary slots used at the destination.";
}
```

```
 container dst-tributary-slots {
 description
 "A list of tributary slots used by the client
 service. Applicable in case of mux services.";
 leaf-list values {
 type uint8;
 description
 "Tributary slot value.";
 reference
 "G.709/Y.1331, February 2016: Interfaces for the
 Optical Transport Network (OTN)";
 }
 }
}

/*
Note: Comment has been given to authors of TE Tunnel model to add
tunnel-types to the model in order to identify the technology
type of the service.

grouping otn-service-type {
 description
 "Identifies the OTN Service type.";
 container otn-service {
 presence "Indicates OTN Service.";
 description
 "Its presence identifies the OTN Service type.";
 }
} // otn-service-type

augment "/te:te/te:tunnels/te:tunnel/te:tunnel-types" {
 description
 "Introduce OTN service type for tunnel.";
 ext:augment-identifier otn-service-type-augment;
 uses otn-service-type;
}
*/

/*
Note: Comment has been given to authors of TE Tunnel model to add
list of endpoints under config to support P2MP tunnel.
*/
augment "/te:te/te:tunnels/te:tunnel/te:config" {
 description
 "Augment with additional parameters required for OTN
 service.";
 //ext:augment-identifier otn-tunnel-endpoint-config-augment;
 uses otn-tunnel-endpoint;
```

```

 }

 augment "/te:te/te:tunnels/te:tunnel/te:state" {
 description
 "Augment with additional parameters required for OTN
 service.";
 //ext:augment-identifier otn-tunnel-endpoint-state-augment;
 uses otn-tunnel-endpoint;
 }

 /*
 Note: Comment has been given to authors of TE Tunnel model to
 add tunnel-lifecycle-event to the model. This notification is
 reported for all lifecycle changes (create, delete, and update)
 to the tunnel or lsp.
 augment "/te:tunnel-lifecycle-event" {
 description
 "OTN service event";
 uses otn-service-type;
 uses otn-tunnel-params;

 list endpoint {
 key
 "endpoint-address tp-id";
 description
 "List of Tunnel Endpoints.";
 uses te:tunnel-endpoint;
 uses otn-tunnel-params;
 }
 }
 */
}
<CODE ENDS>

```

### 3.6. Transport Types YANG Code

```

<CODE BEGINS> file "ietf-transport-types@2017-05-25.yang"

module ietf-transport-types {
 namespace "urn:ietf:params:xml:ns:yang:ietf-transport-types";
 prefix "tran-types";

 organization
 "IETF CCAMP Working Group";
 contact
 "WG Web: <http://tools.ietf.org/wg/ccamp/>"

```

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<mailto:victor.lopezalvarez@telefonica.com>

Editor: Yunbo Li  
<mailto:liyunbo@chinamobile.com>";

description  
"This module defines transport types.";

revision "2017-05-25" {  
  description  
    "Revision 0.3";  
  reference  
    "draft-sharma-ccamp-otn-tunnel-model-02.txt";  
}

identity tributary-slot-granularity {  
  description  
    "Tributary slot granularity.";  
  reference  
    "G.709/Y.1331, February 2016: Interfaces for the  
      Optical Transport Network (OTN)";  
}

identity tsg-1.25G {  
  base tributary-slot-granularity;  
  description  
    "1.25G tributary slot granularity.";  
}

identity tsg-2.5G {



```
 base tributary-slot-granularity;
 description
 "2.5G tributary slot granularity.";
 }

 identity tributary-protocol-type {
 description
 "Base identity for protocol framing used by
 tributary signals.";
 }

 identity prot-OTU1 {
 base tributary-protocol-type;
 description
 "OTU1 protocol (2.66G)";
 }

 /*
 identity prot-OTU1e {
 base tributary-protocol-type;
 description
 "OTU1e type (11.04G)";
 }

 identity prot-OTU1f {
 base tributary-protocol-type;
 description
 "OTU1f type (11.27G)";
 }
 */

 identity prot-OTU2 {
 base tributary-protocol-type;
 description
 "OTU2 type (10.70G)";
 }

 identity prot-OTU2e {
 base tributary-protocol-type;
 description
 "OTU2e type (11.09G)";
 }

 /*
 identity prot-OTU2f {
 base tributary-protocol-type;
 description
 "OTU2f type (11.31G)";
 }
 */
```

```
*/

identity prot-OTU3 {
 base tributary-protocol-type;
 description
 "OTU3 type (43.01G)";
}

/*
identity prot-OTU3e1 {
 base tributary-protocol-type;
 description
 "OTU3e1 type (44.57G)";
}

identity prot-OTU3e2 {
 base tributary-protocol-type;
 description
 "OTU3e2 type (44.58G)";
}
*/

identity prot-OTU4 {
 base tributary-protocol-type;
 description
 "OTU4 type (111.80G)";
}

identity prot-OTUCn {
 base tributary-protocol-type;
 description
 "OTUCn type (beyond 100G)";
}

identity prot-ODU0 {
 base tributary-protocol-type;
 description
 "ODU0 protocol (1.24G).";
}

identity prot-ODU1 {
 base tributary-protocol-type;
 description
 "ODU1 protocol (2.49G).";
}

/*
identity prot-ODU1e {
```

```
 base tributary-protocol-type;
 description
 "ODU1e protocol (10.35G).";
 }

 identity prot-ODU1f {
 base tributary-protocol-type;
 description
 "ODU1f protocol (10.56G).";
 }
 */

 identity prot-ODU2 {
 base tributary-protocol-type;
 description
 "ODU2 protocol (10.03G).";
 }

 identity prot-ODU2e {
 base tributary-protocol-type;
 description
 "ODU2e protocol (10.39G).";
 }

 /*
 identity prot-ODU2f {
 base tributary-protocol-type;
 description
 "ODU2f protocol (10.60G).";
 }
 */

 identity prot-ODU3 {
 base tributary-protocol-type;
 description
 "ODU3 protocol (40.31G).";
 }

 /*
 identity prot-ODU3e1 {
 base tributary-protocol-type;
 description
 "ODU3e1 protocol (41.77G).";
 }

 identity prot-ODU3e2 {
 base tributary-protocol-type;
 description
```

```
 "ODU3e2 protocol (41.78G).";
 }
 */

 identity prot-ODU4 {
 base tributary-protocol-type;
 description
 "ODU4 protocol (104.79G).";
 }

 identity prot-ODUFlex-cbr {
 base tributary-protocol-type;
 description
 "ODU Flex CBR protocol for transporting constant bit
 rate signal.";
 }

 identity prot-ODUFlex-gfp {
 base tributary-protocol-type;
 description
 "ODU Flex GFP protocol for transporting stream of packets
 using Generic Framing Procedure.";
 }

 identity prot-ODUCn {
 base tributary-protocol-type;
 description
 "ODUCn protocol (beyond 100G).";
 }

 identity prot-1GbE {
 base tributary-protocol-type;
 description
 "1G Ethernet protocol";
 }

 identity prot-10GbE-LAN {
 base tributary-protocol-type;
 description
 "10G Ethernet LAN protocol";
 }

 identity prot-40GbE {
 base tributary-protocol-type;
 description
 "40G Ethernet protocol";
 }
}
```

```
identity prot-100GbE {
 base tributary-protocol-type;
 description
 "100G Ethernet protocol";
}

identity client-signal {
 description
 "Base identity from which specific client signals for the
 tunnel are derived.";
}

identity client-signal-1GbE {
 base client-signal;
 description
 "Client signal type of 1GbE";
}

identity client-signal-10GbE-LAN {
 base client-signal;
 description
 "Client signal type of 10GbE LAN";
}

identity client-signal-10GbE-WAN {
 base client-signal;
 description
 "Client signal type of 10GbE WAN";
}

identity client-signal-40GbE {
 base client-signal;
 description
 "Client signal type of 40GbE";
}

identity client-signal-100GbE {
 base client-signal;
 description
 "Client signal type of 100GbE";
}

identity client-signal-OC3_STM1 {
 base client-signal;
 description
 "Client signal type of OC3 & STM1";
}
```

```
identity client-signal-OC12_STM4 {
 base client-signal;
 description
 "Client signal type of OC12 & STM4";
}

identity client-signal-OC48_STM16 {
 base client-signal;
 description
 "Client signal type of OC48 & STM16";
}

identity client-signal-OC192_STM64 {
 base client-signal;
 description
 "Client signal type of OC192 & STM64";
}

identity client-signal-OC768_STM256 {
 base client-signal;
 description
 "Client signal type of OC768 & STM256";
}

identity client-signal-ODU0 {
 base client-signal;
 description
 "Client signal type of ODU0 (1.24G)";
}

identity client-signal-ODU1 {
 base client-signal;
 description
 "ODU1 protocol (2.49G)";
}

identity client-signal-ODU2 {
 base client-signal;
 description
 "Client signal type of ODU2 (10.03G)";
}

identity client-signal-ODU2e {
 base client-signal;
 description
 "Client signal type of ODU2e (10.39G)";
}
```

```
identity client-signal-ODU3 {
 base client-signal;
 description
 "Client signal type of ODU3 (40.31G)";
}

/*
identity client-signal-ODU3e2 {
 base client-signal;
 description
 "Client signal type of ODU3e2 (41.78G)";
}
*/

identity client-signal-ODU4 {
 base client-signal;
 description
 "Client signal type of ODU4 (104.79G)";
}

identity client-signal-ODUFlex-cbr {
 base client-signal;
 description
 "Client signal type of ODU Flex CBR";
}

identity client-signal-ODUFlex-gfp {
 base client-signal;
 description
 "Client signal type of ODU Flex GFP";
}

identity client-signal-ODUCn {
 base client-signal;
 description
 "Client signal type of ODUCn (beyond 100G).";
}

identity client-signal-FC400 {
 base client-signal;
 description
 "Client signal type of Fibre Channel FC400.";
}

identity client-signal-FC800 {
 base client-signal;
 description
 "Client signal type of Fibre Channel FC800.";
```

```
 }

 identity client-signal-FICON-4G {
 base client-signal;
 description
 "Client signal type of Fibre Connection 4G.";
 }

 identity client-signal-FICON-8G {
 base client-signal;
 description
 "Client signal type of Fibre Connection 8G.";
 }
}
<CODE ENDS>
```

#### 4. Security Considerations

TBD.

#### 5. IANA Considerations

TBD.

#### 6. Acknowledgements

TBD.

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## 8. Normative References

- [I-D.ietf-netmod-rfc6087bis]  
Bierman, A., "Guidelines for Authors and Reviewers of YANG Data Model Documents", draft-ietf-netmod-rfc6087bis-12 (work in progress), March 2017.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.

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## Abstract

This document describes the scenarios, simulation and suggestions for the "Centrally Control Dynamic Routing (CCDR)" architecture, which integrates the merit of traditional distributed protocols (IGP/BGP), and the power of centrally control technologies (PCE/SDN) to provide one feasible traffic engineering solution in various complex scenarios for the service provider.

Traditional MPLS-TE solution is mainly used in static network planning scenario and is difficult to meet the QoS assurance requirements in real-time traffic network. With the emerge of SDN concept and related technologies, it is possible to simplify the complexity of distributed control protocol, utilize the global view of network condition, give more efficient solution for traffic engineering in various complex scenarios.

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## 1. Introduction

Internet network is composed mainly tens of thousands of routers that run distributed protocol to exchange the reachability information between them. The path for the destination network is mainly calculated and controlled by the traditional IGP protocols. These distributed protocols are robust enough to support the current

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evolution of Internet but has some difficulties when the application requires the end-to-end QoS performance, or the service provider wants to maximize the links utilization within their network.

MPLS-TE technology is one perfect solution for the finely planned network but it will put heavy burden on the router when we use it to solve the dynamic QoS assurance requirements within real time traffic network.

SR(Segment Routing) is another prominent solution that integrates some merits of traditional distributed protocol and the advantages of centrally control mode, but it requires the underlying network, especially the provider edge router to do label push and pop action in-depth, and need some complex solutions for co-exist with the Non-SR network. Finally, it can only maneuver the end-to-end path for MPLS and IPv6 traffic via different mechanisms.

The advantage of MPLS is mainly for traffic isolation, such as the L2/L3 VPN service deployments, but most of the current application requirements are only for high performances end-to-end QoS assurance. Without the help of centrally control architecture, the service provider almost can't make such SLA guarantees upon the real time traffic situation.

This draft gives some scenarios that the centrally control dynamic routing (CCDR) architecture can easily solve, without adding more extra burdening on the router. It also gives the PCE algorithm results under the similar topology, traffic pattern and network size to illustrate the applicability of CCDR architecture. Finally, it gives some suggestions for the implementation and deployment of CCDR.

## 2. CCDR Scenarios.

The following sections describe some scenarios that the CCDR architecture is suitable for deployment.

### 2.1. Qos Assurance for Hybrid Cloud-based Application.

With the emerge of cloud computing technologies, enterprises are putting more and more services on the public oriented service infrastructure, but keep still some core services within their network. The bandwidth requirements between the private cloud and the public cloud are occasionally and the background traffic between these two sites varied from time to time. Enterprise cloud

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 applications just want to invoke the network capabilities to make  
 the end-to-end QoS assurance on demand. Otherwise, the traffic  
 should be controlled by the distributed protocol.

CCDR, which integrates the merits of distributed protocol and the  
 power of centrally control, is suitable for this scenario. The  
 possible solution architecture is illustrated below:

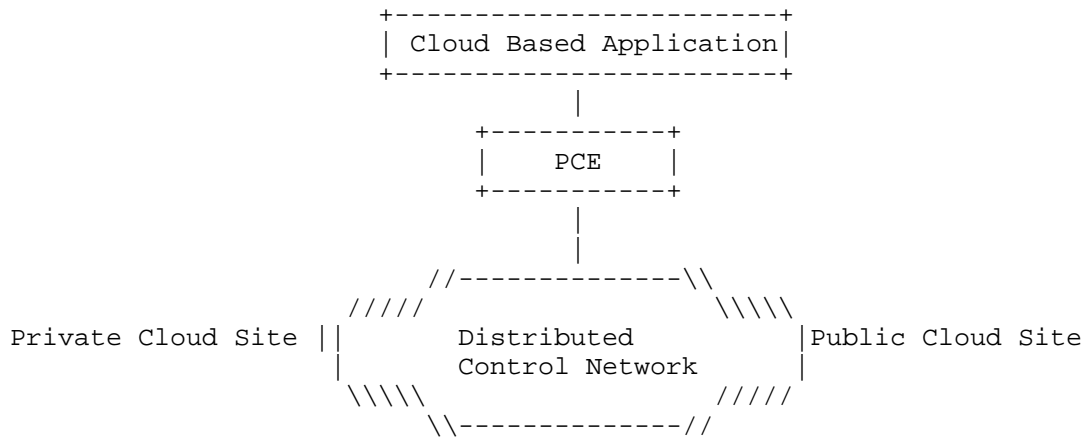


Fig.1 Hybrid Cloud Communication Scenario

By default, the traffic path between the private cloud site and  
 public cloud site will be determined by the distributed control  
 network. When some applications require the end-to-end QoS assurance,  
 it can send these requirements to PCE, let PCE compute one e2e path  
 which is based on the underlying network topology and the real  
 traffic information, to accommodate the application's bandwidth  
 requirements. The proposed solution can refer the draft [draft-wang-  
 teas-pce-native-ip]. Section 4 describes the detail simulation  
 process and the results.

## 2.2. Increase link utilization based on tidal phenomena.

Currently, the network topology within MAN is generally in star mode  
 as illustrated in Fig.2, with the different devices connect  
 different customer types. The traffic pattern of these customers  
 demonstrates some tidal phenomena that the links between the CR/BRAS  
 and CR/SR will experience congestion in different periods because  
 the subscribers under BRAS often use the network at night and the  
 dedicated line users under SR often use the network during the  
 daytime. The uplink between BRAS/SR and CR must satisfy the maximum  
 traffic pattern between them and this causes the links  
 underutilization.

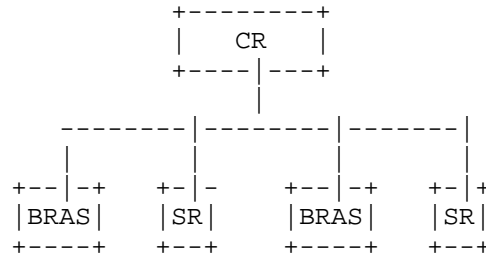


Fig.2 STAR-style network topology within MAN

If we can consider link the BRAS/SR with local loop, and control the MAN with the CCDR architecture, we can exploit the tidal phenomena between BRAS/CR and SR/CR links, increase the efficiency of them.

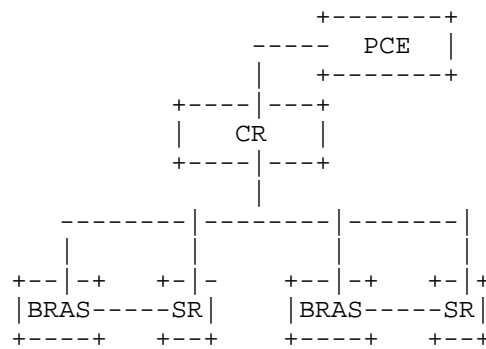
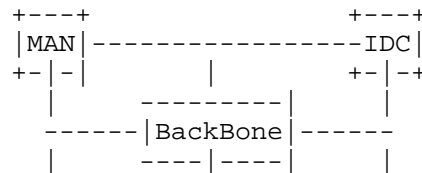


Fig.3 Increase the link utilization via CCDR

### 2.3. Traffic engineering for IDC/MAN asymmetric link

The operator's networks are often comprised by tens of different domains, interconnected with each other, form very complex topology that illustrated in Fig.4. Due to the traffic pattern to/from MAN and IDC, the links between them are often in asymmetric style. It is almost impossible to balance the utilization of these links via the distributed protocol, but this unbalance phenomenon can be overcome via the CCDR architecture.



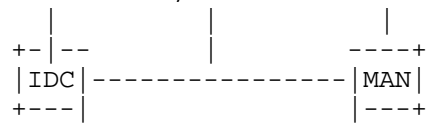


Fig.4 TE within Complex Multi-Domain topology

#### 2.4. Network temporal congestion elimination.

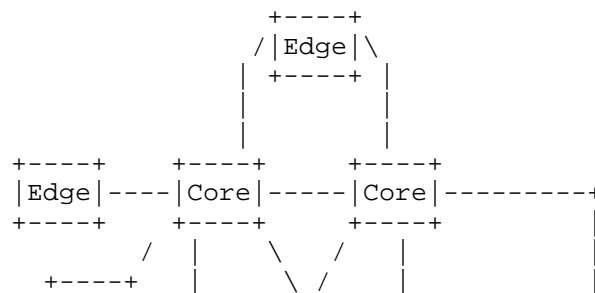
In more general situation, there are often temporal congestion periods within part of the service provider's network. Such congestion phenomena will appear repeatedly and if the service provider has some methods to mitigate it, it will certainly increase the satisfaction degree of their customer. CCDR is also suitable for such scenario that the traditional distributed protocol will process most of the traffic forwarding and the controller will schedule some traffic out of the congestion links to lower the utilization of them. Section 4 describes the simulation process and results about such scenario.

#### 3. CCDR Simulation.

The following sections describe the topology, traffic matrix, end-to-end path optimization and congestion elimination in CCDR simulation.

##### 3.1. Topology Simulation.

The network topology mainly contains nodes and links information. Nodes used in simulation have two types: core nodes and edge nodes. The core nodes are fully linked to each other. The edge nodes are connected only with some of the core nodes. Fig.5 is a topology example of 4 core nodes and 5 edge nodes. In CCDR simulation, 100 core nodes and 400 edge nodes are generated.





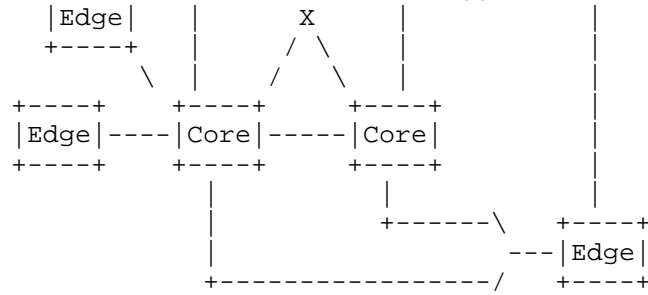


Fig.5 Topology of simulation

The number of links connecting one edge node to the set of core nodes is randomly between 2 to 30, and the total number of links is more than 20000. Each link has its congestion threshold.

### 3.2. Traffic Matrix Simulation.

The traffic matrix is generated based on the link capacity of topology. It can result in many kinds of situations, such as congestion, mild congestion and non-congestion.

In CCDR simulation, the traffic matrix is 500\*500. About 20% links are overloaded when the Open Shortest Path First (OSPF) protocol is used in the network.

### 3.3. CCDR End-to-End Path Optimization

The CCDR end-to-end path optimization is to find the best end-to-end path which is the lowest in metric value and each link of the path is far below link's threshold. Based on the current state of the network, PCE within CCDR architecture combines the shortest path algorithm with penalty theory of classical optimization and graph theory.

Given background traffic matrix which is unscheduled, when a set of new flows comes into the network, the end-to-end path optimization finds the optimal paths for them. The selected paths bring the least congestion degree to the network.

The link utilization increment degree (UID) when the new flows are added into the network is shown in Fig.6. The first graph in Fig.6 is the UID with OSPF and the second graph is the UID with CCDR end-to-end path optimization. The average UID of graph one is more than 30%. After path optimization, the average UID is less than 5%. The results show that the CCDR end-to-end path optimization has an eye-catching decreasing in UID relative to the path chosen based on OSPF.

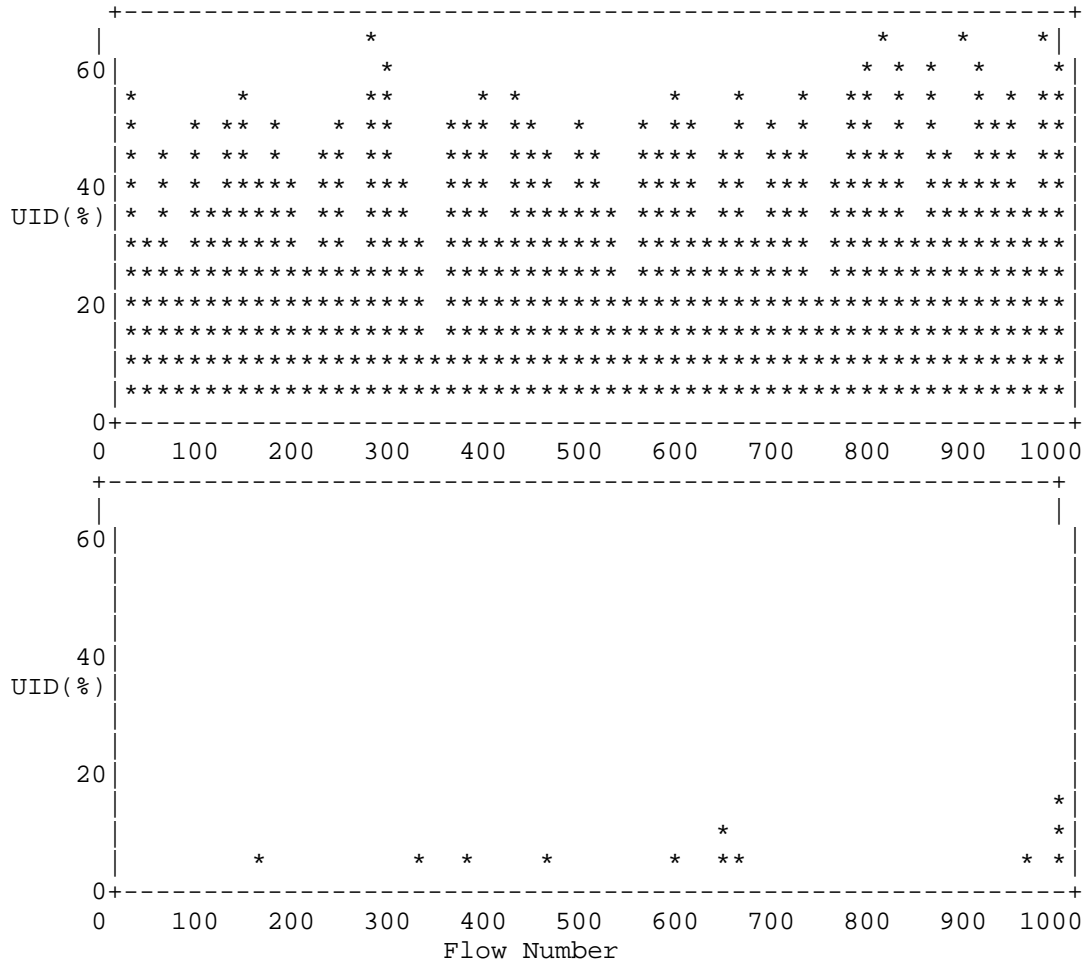


Fig.6 Simulation result with congestion elimination

### 3.4. Network temporal congestion elimination

Different degree of network congestion is simulated. The congestion degree (CD) is defined as the link utilization beyond its threshold.

The CCDR congestion elimination performance is shown in Fig.7. The first graph is the congestion degree before the process of congestion elimination. The average CD of all congested links is more than 10%. The second graph shown in Fig.7 is the congestion degree after congestion elimination process. It shows only 12 links among totally 20000 links exceed the threshold, and all the congestion degree is less than 3%. Thus, after schedule of the traffic in congestion paths, the degree of network congestion is greatly eliminated and the network utilization is in balance.

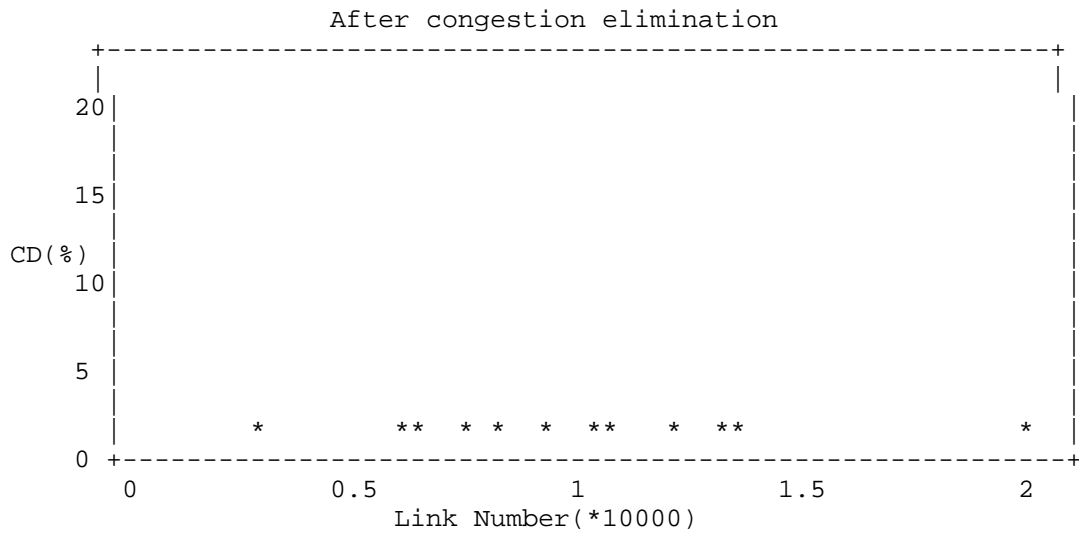
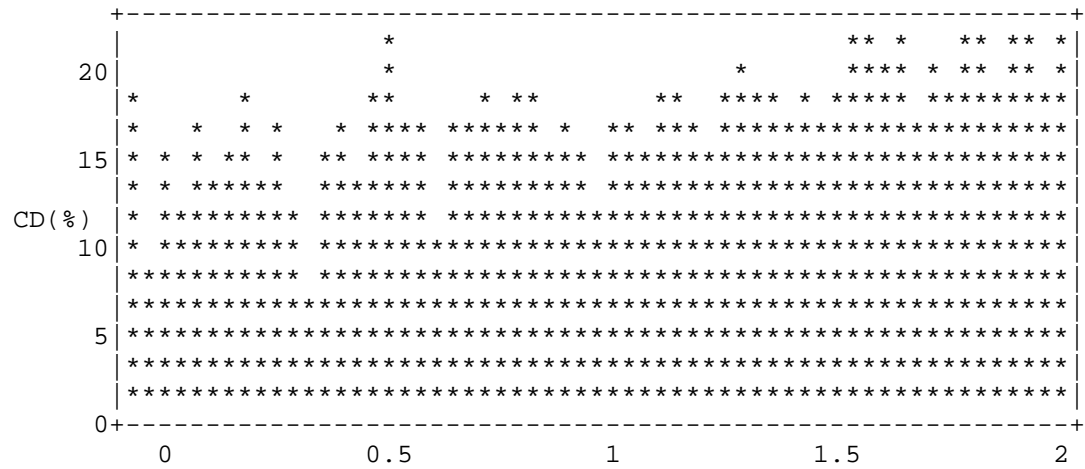


Fig.7 Simulation result with congestion elimination

#### 4. CCDR Deployment Consideration.

With the above CCDR scenarios and simulation results, we can know it is necessary and feasible to find one general solution to cope with various complex situations for the most complex optimal path computation in centrally manner based on the underlay network topology and the real time traffic.

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[draft-wang-teas-native-ip] gives the principle solution for above scenarios, such thoughts can be extended to cover requirements that are more concretes in future.

## 5. Security Considerations

TBD

## 6. IANA Considerations

TBD

## 7. Conclusions

TBD

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Applicability of YANG models for Abstraction and Control of Traffic  
Engineered Networks

draft-zhang-teas-actn-yang-05

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#### Abstract

Abstraction and Control of TE Networks (ACTN) refers to the set of virtual network operations needed to orchestrate, control and manage large-scale multi-domain TE networks, so as to facilitate network programmability, automation, efficient resource sharing, and end-to-end virtual service aware connectivity and network function virtualization services.

This document explains how the different types of YANG models defined in the Operations and Management Area and in the Routing Area are applicable to the ACTN framework. This document also shows how the ACTN architecture can be satisfied using classes of data model that have already been defined, and discusses the applicability of specific data models that are under development. It also highlights where new data models may need to be developed.

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## 1. Introduction

Abstraction and Control of TE Networks (ACTN) describes a method for operating a Traffic Engineered (TE) network (such as an MPLS-TE network or a layer 1 transport network) to provide connectivity and virtual network services for customers of the TE network. The services provided can be tuned to meet the requirements (such as traffic patterns, quality, and reliability) of the applications hosted by the customers. More details about ACTN can be found in Section 2.

Data models are a representation of objects that can be configured or monitored within a system. Within the IETF, YANG [RFC6020] is the language of choice for documenting data models, and YANG models have been produced to allow configuration or modelling of a variety of network devices, protocol instances, and network services. YANG data models have been classified in [Netmod-Yang-Model-Classification] and [Service-YANG].

This document shows how the ACTN architecture can be satisfied using classes of data model that have already been defined, and discusses the applicability of specific data models that are under development. It also highlights where new data models may need to be developed.

## 2. Abstraction and Control of TE Networks (ACTN) Architecture

[ACTN-Requirements] describes the high-level ACTN requirements.  
[ACTN-Frame] describes the architecture model for ACTN including the

entities (Customer Network Controller (CNC), Multi-domain Service Coordinator (MDSC), and Physical Network Controller (PNC)) and their interfaces.

Figure 1 depicts a high-level control and interface architecture for ACTN and is a reproduction of Figure 3 from [ACTN-Frame]. A number of key ACTN interfaces exist for deployment and operation of ACTN-based networks. These are highlighted in Figure 1 (ACTN Interfaces) below:

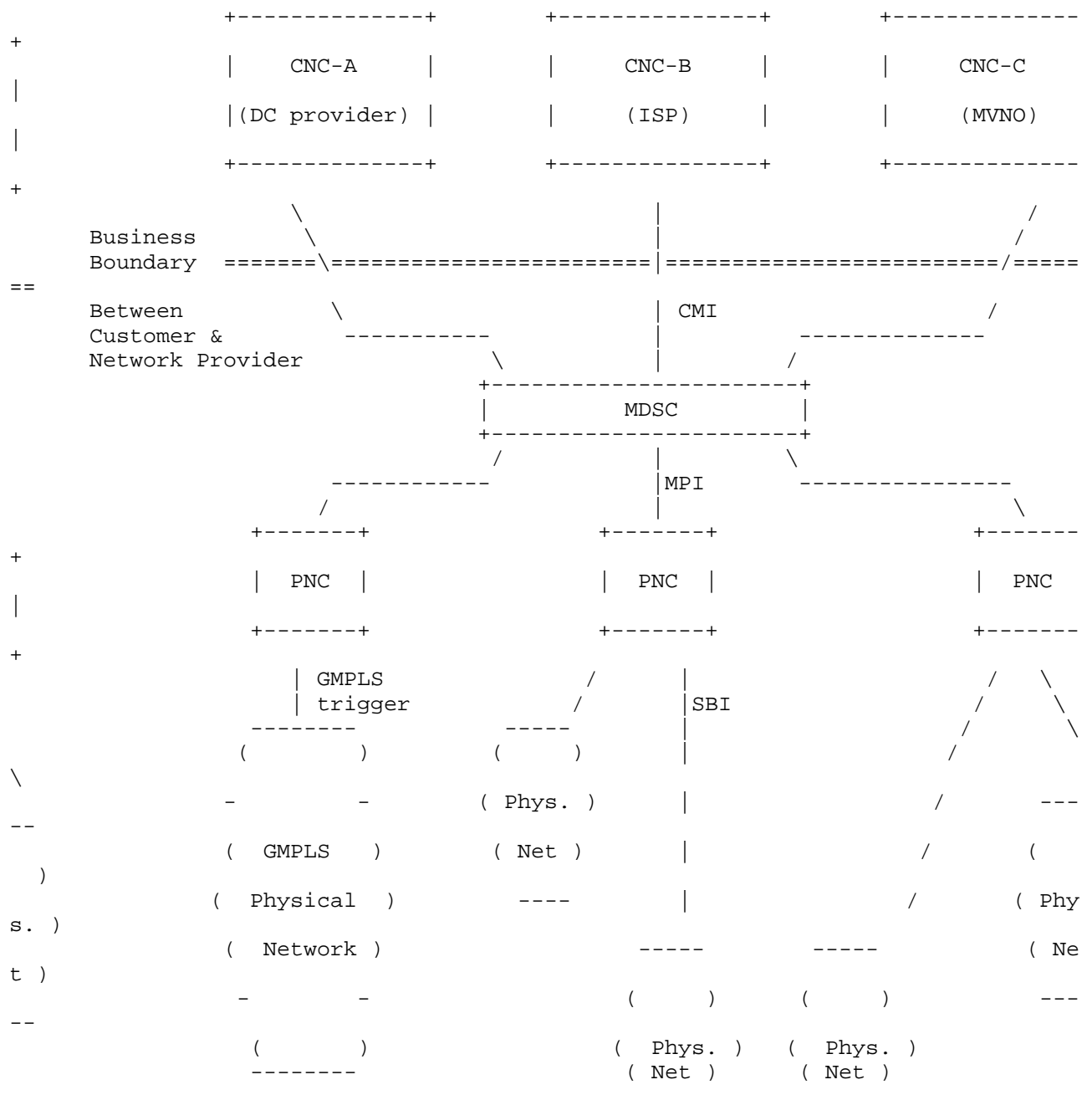


Figure 1 : ACTN Interfaces

The interfaces and functions are described below (without modifying the definitions) in [ACTN-Frame]:



- . The CNC-MDSC Interface (CMI) is an interface between a Customer Network Controller and a Multi Domain Service Controller. The interface will communicate the service request or application demand. A request will include specific service properties, for example, services type, bandwidth and constraint information. These constraints SHOULD be measurable by MDSC and therefore visible to CNC via CMI. The CNC can also request the creation of the virtual network based on underlying physical resources to provide network services for the applications. The CNC can provide the end-point information/characteristics, traffic matrix specifying specific customer constraints. The MDSC may also report potential network topology availability if queried for current capability from the Customer Network Controller.
- . The MDSC-PNC Interface (MPI) is an interface between a Multi Domain Service Coordinator and a Physical Network Controller. It allows the MDSC to communicate requests to create/delete connectivity or to modify bandwidth reservations in the physical network. In multi-domain environments, each PNC is responsible for a separate domain. The MDSC needs to establish multiple MPIs, one for each PNC and perform coordination between them to provide cross-domain connectivity.
- . The South-Bound Interface (SBI) is the provisioning interface for creating forwarding state in the physical network, requested via the Physical Network Controller. The SBI is not in the scope of ACTN, however, it is included in this document so that it can be compared to models in [Service-Yang].

### 3. Service Models

[Service-YANG] introduces a reference architecture to explain the nature and usage of service YANG models in the context of service orchestration. Figure 2 below depicts this relationship and is a reproduction of Figure 2 from [Service-YANG]. Four models depicted in Figure 2 are defined as follows:

- . Customer Service Model: A customer service model is used to describe a service as offer or delivered to a customer by a network operator.
- . Service Delivery Model: A service delivery model is used by a network operator to define and configure how a service is provided by the network.
- . Network Configuration Model: A network configuration model is used by a network orchestrator to provide network-level configuration model to a controller.

- . Device Configuration Model: A device configuration model is used by a controller to configure physical network elements.

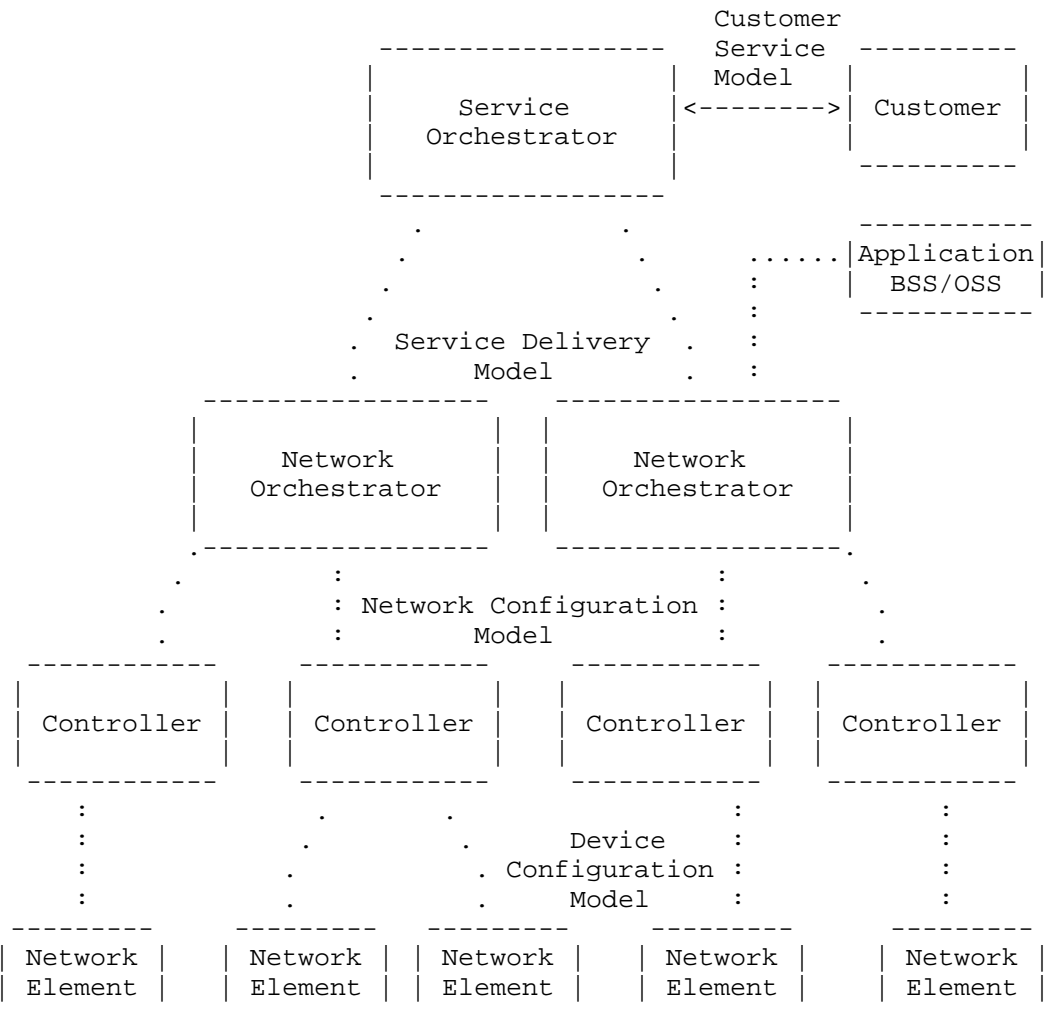


Figure 2: An SDN Architecture with a Service Orchestrator

#### 4. Service Model Mapping to ACTN

YANG models coupled with the RESTCONF/NETCONF protocol [Netconf][Restconf] provides solutions for the ACTN framework. This section explains which types of YANG models apply to each of the ACTN interfaces.

Refer to Figure 5 of [ACTN-Frame] for details of the mapping between ACTN functions and service models. In summary, the following mappings are held between Service Yang Models and the ACTN interfaces.

- o Customer Service Model <-> CMI
- o Network Configuration Model <-> MPI
- o Device Configuration Model <-> SBI

#### 4.1. Customer Service Models in the ACTN Architecture (CMI)

Customer Service Models, which are used between a customer and a service orchestrator as in [Service-YANG], should be used between the CNC and MDSC (e.g., CMI) serving as providing a simple intent-like model/interface.

Among the key functions of Customer Service Models on the CMI is the service request. A request will include specific service properties, including: service type and its characteristics, bandwidth, constraint information, and end-point characteristics.

The following table provides a list of functions needed to build the CMI. They are mapped with Customer Service Models.

| Function                            | Yang Model                |
|-------------------------------------|---------------------------|
| Transport Service Request           | [Transport-Service-Model] |
| VN Service Request & Instantiation  | [ACTN-VN-YANG]            |
| VN Path Computation Request         | [ACTN-VN-YANG]*           |
| VN Performance Monitoring Telemetry | [ACTN-PM-Telemetry]**     |
| Topology Abstraction                | [TE-topology]             |

\*VN Path computation request in the CMI context means network path computation request based on customer service connectivity request constraints prior to the instantiation of a VN creation.

\*\*ietf-actn-te-kpi-telemetry model describes performance telemetry for ACTN VN model. This module also allows autonomic traffic engineering scaling intent configuration mechanism on the VN level. Scale in/out criteria might be used for network autonomics in order the controller to react to a certain set of variations in monitored parameters. Moreover, this module also provides mechanism to define

aggregated telemetry parameters as a grouping of underlying VN level telemetry parameters.

#### 4.2. Service Delivery Models in ACTN Architecture

The Service Delivery Models where the service orchestration and the network orchestration could be implemented as separate components as seen in [Service-YANG]. This is also known as Network Service Models. On the other hand, from an ACTN architecture point of view, the service delivery model between the service orchestrator and the network orchestrator is an internal interface between sub-components of the MDSC in a single MDSC model.

In the MDSC hierarchical model where there are multiple MDSCs, the interface between the top MDSC and the bottom MDSC can be mapped to service delivery models.

#### 4.3. Network Configuration Models in ACTN Architecture (MPI)

The Network Configuration Models is used between the network orchestrator and the controller in [Service-YANG]. In ACTN, this model is used primarily between a MDSC and a PNC. The Network Configuration Model can be also used for the foundation of more advanced models, like hierarchical MDSCs (see Section 4.5)

The Network Configuration Model captures the parameters which are network wide information.

The following table provides a list of functions needed to build the MPI. They are mapped with Network Configuration Yang Models. Note that various Yang models are work in progress.

| Function                        | Yang Model              |
|---------------------------------|-------------------------|
| Configuration Scheduling        | [Schedule]              |
| Path computation                | [PATH_COMPUTATION-API]* |
| Path Provisioning               | [TE-Tunnel]**           |
| Topology Abstraction            | [TE-topology]           |
| Tunnel PM Telemetry             | [ACTN-PM-Telemetry]***  |
| Service Provisioning            | TBD****                 |
| OTN Topology Abstraction        | [OTN-YANG]              |
| WSON Topology Abstraction       | [WSON-YANG]             |
| Flexi-grid Topology Abstraction | [Flexi-YANG]            |
| ODU Tunnel Model                | [ODU-Tunnel]            |



|                         |                    |
|-------------------------|--------------------|
| WSON TE Tunnel Model    | [WSON-Tunnel]      |
| Flexi-grid Tunnel Model | [Flexigrid-Tunnel] |

\* Related draft is presenting use cases for path computation API, and Yang related model is foreseen to be added.

\*\* Note that path provisioning function is provided by ietf-te module in [TE-Tunnel].

\*\* ietf-actn-te-kpi-telemetry model describes performance telemetry for TE-tunnel model. This module also allows autonomic traffic engineering scaling intent configuration mechanism on the TE-tunnel level. Various conditions can be set for auto-scaling based on the telemetry data.

\*\*\*\* This function needs to be investigated further. This can be a part of [TE-Tunnel] which is to be determined. Service provisioning is an optional function that builds on top the path provisioning one.

Path provisioning and Topology abstraction functions are mandatory in any case, while Path Computation may be mandatory or optional depending on the type of topology abstraction used. Details of this topic are discussed in [ACTN-Abstraction].

Telemetry may also be an optional function.

#### 4.4. Device Models in ACTN Architecture (SBI)

For the device YANG models are used for per-device configuration purpose, they can be used between the PNC and the physical network/devices. Note that SBI is not in the scope of ACTN. This section is provided to give some examples of YANG-based Device Models. An example of Device Models is ietf-te-device yang module defined in [TE-tunnel].

## 5. Examples of Using Different Types of YANG Models

### 5.1. Simple Connectivity Examples

The data model in [Transport-Service-Model] provides an intent-like connectivity service model which can be used in connection-oriented networks.

It would be used as follows in the ACTN architecture:

- . A CNC uses this service model to specify the two client nodes that are to be connected, and also indicates the amount of traffic (i.e., the bandwidth required) and payload type. What may be additionally specified is the SLA that describes the required quality and resilience of the service.
- . The MDSC uses the information in the request to pick the right network (domain) and also to select the provider edge nodes corresponding to the customer edge nodes.

If there are multiple domains, then the MDSC needs to coordinate across domains to set up network tunnels to deliver a service. Thus coordination includes, but is not limited to, picking the right domain sequence to deliver a service. Before it can perform such functions, it needs to get the topology information from each PNC, using topology YANG models such as [te-topology]. The topology reported from PNC to MDSC can either be abstract or non-abstract.

Additionally, an MDSC can initiate the creation of a tunnel (or tunnel segment) in order to fulfill the service request from CNC based on path computation upon the overall topology information it synthesized from different PNCs. The based model that can cater this purpose is the te-tunnel model specified in [te-tunnel].

- . Then, the PNC needs to decide the explicit route of such a tunnel or tunnel segment (in case of multiple domains), and create such a tunnel using protocols such as PCEP and RSVP-TE or using per-hop configuration.

### 5.2. VN service example

The service model defined in [ACTN-VN-YANG] describes a virtual network (VN) as a service which is a set of multiple connectivity services:

- . A CNC will request VN to the MDSC by specifying a list of VN members. Each VN member specifies either a single connectivity service, or a source with multiple potential destination points in the case that the precise destination sites are to be determined by MDSC.
  - o In the first case, the procedure is the same as the connectivity service, except that in this case, there is a list of connections requested.
  - o In the second case, where the CNC requests the MDSC to select the right destination out of a list of candidates, the MDSC needs to choose the best candidate and reply with the chosen destination for a given VN member. After this is selected, the connectivity request setup procedure is the same as in the connectivity-as-a-service example.

After the VN is set up, a successful reply message is sent from MDSC to CNC, indicating the VN is ready. This message can also be achieved by using the model defined in [ACTN-VN-YANG].

### 5.3. Data Center-Interconnection Example

This section describes more concretely how existing YANG models described in Section 4 map to an ACTN data center interconnection use case. Figure 3 shows a use-case which shows service policy-driven Data Center selection and is a reproduction of Figure A.1 from [ACTN-Info].

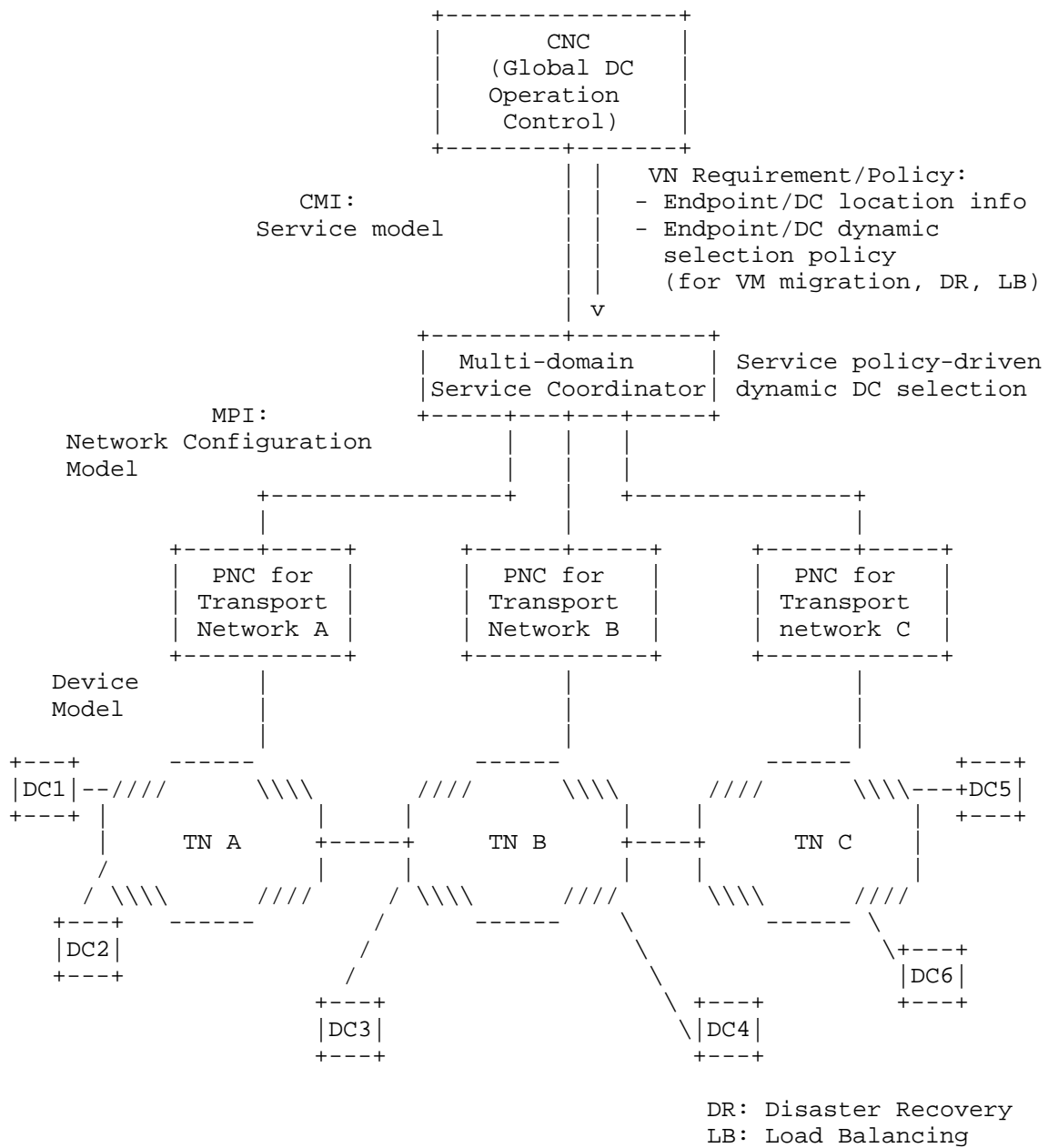


Figure 3: Service Policy-driven Data Center Selection

Figure 3 shows how VN policies from the CNC (Global Data Center Operation) are incorporated by the MDSC to support multi-destination applications. Multi-destination applications refer to applications in which the selection of the destination of a network path for a given source needs to be decided dynamically to support such applications.

Data Center selection problems arise for VM mobility, disaster recovery and load balancing cases. VN's policy plays an important role for virtual network operation. Policy can be static or dynamic. Dynamic policy for data center selection may be placed as a result of utilization of data center resources supporting VMs. The MDSC would then incorporate this information to meet the objective of this application.

#### 5.3.1. CMI (CNC-MDSC Interface)

[ACTN-VN-YANG] is used to express the definition of a VN, its VN creation request, the service objectives (metrics, QoS parameters, etc.), dynamic service policy when VM needs to be moved from one Data Center to another Data Center, etc. This service model is used between the CNC and the MDSC (CMI). The CNC in this use-case is an external entity that wants to create a VN and operates on the VN.

#### 5.3.2. MPI (MDSC-PNC Interface)

The Network Configuration Model is used between the MDSC and the PNCs. Based on the Customer Service Model's request, the MDSC will need to translate the service model into the network configuration model to instantiate a set of multi-domain connections between the prescribed sources and the destinations. The MDSC will also need to dynamically interact with the CNC for dynamic policy changes initiated by the CNC. Upon the determination of the multi-domain connections, the MDSC will need to use the network configuration model such as [TE-Tunnel] to interact with each PNC involved on the path. [TE-Topology] is used to for the purpose of underlying domain network abstraction from the PNC to the MDSC.

#### 5.3.3. PDI (PNC-Device interface)

The Device Model can be used between the PNC and its underlying devices that are controlled by the PNC. The PNC will need to trigger signaling using any mechanisms it employs (e.g. [RSVP-TE-YANG]) to provision its domain path segment. There can be a plethora of choices how to control/manage its domain network. The PNC is responsible to abstract its domain network resources and update it

to the MDSC. Note that this interface is not in the scope of ACTN. This section is provided just for an illustration purpose.

## 6. Security

This document is an informational draft. When the models mentioned in this draft are implemented, detailed security consideration will be given in such work.

How security fits into the whole architecture has the following components:

- the use of Restconf security between components
- the use of authentication and policy to govern which services can be requested by different parties.
- how security may be requested as an element of a service and mapped down to protocol security mechanisms as well as separation (slicing) of physical resources)

## 7. Acknowledgements

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