CCAMP Working Group
Internet-Draft
Intended status: Informational
Expires: March 26, 2021

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September 22, 2020

A YANG Data Model for Flexi-Grid Optical Networks
draft-ietf-ccamp-flexigrid-yang-07

Abstract

This document defines a YANG module for managing flexi-grid optical networks. The model defined in this document specifies a flexi-grid traffic engineering database that is used to describe the topology of a flexi-grid network. It is based on and augments existing YANG models that describe network and traffic engineering topologies.

A partner document defines a second YANG module for flexi-grid media channels, i.e., the paths from source to destination through a number of intermediate nodes.

Status of This Memo

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1. Introduction

The flexible grid (flexi-grid) optical network technology defined by the International Telecommunication Union Telecommunication Standardization Sector (ITU-T) and documented in Recommendation G.694.1 [G.694.1] and G.872 [G.872] provides an enhanced Dense Wavelength Division Multiplexing (DWDM) grid by defining a set of nominal central frequencies, channel spacings, and the concept of the "frequency slot". In such an environment, a data-plane connection is switched based on allocated, variable-sized frequency ranges within the optical spectrum, creating what is known as a flexible grid (flexi-grid). This technology increases both transport network scalability and flexibility, allowing the optimization of bandwidth usage.

[RFC7698] provides a framework GMPLS-Based control of flexi-grid DWDM networks while [RFC7699] defines generalized labels for the use in flexi-grid in GMPLS networks.

This document presents a YANG [RFC7950] model for flexi-grid objects in the dynamic optical network, including the nodes, transponders and links between them, as well as how such links interconnect nodes and transponders.

The YANG model for flexi-grid networks allows the representation of the flexi-grid optical layer of a network, combined with the underlying physical layer.

This document identifies the flexi-grid components, parameters and their values, characterizes the features and the performances of the flexi-grid elements. An application example is provided towards the end of the document to better understand their utility.

A partner document defines a second YANG module that described flexi-grid tunnels, i.e., the paths from source to destination through a number of intermediate nodes [I-D.ietf-ccamp-flexigrid-media-channel-yang].

2. Conventions

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. Terminology

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:

- client

- server

- augment

- data model

- data node

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

- configuration data

- state data

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

4. Tree Diagram

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

4.1. 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 Figure 1. It uses prefixes from [I-D.ietf-ccamp-layer0-types], [RFC8345], and [RFC8795].

Prefix	YANG module	Reference
l0-types	ietf-layer0-types	[RFCXXXX]
flexi-grid	ietf-flexi-grid-topology	[RFCYYYY]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[RFC8795]

Figure 1: Prefixes and Corresponding YANG modules

RFC Editor Note: Please replace XXXX with the RFC numbers assigned to draft-ietf-ccamp-layer0-types. Please replace YYYY with the RFC number assigned to this document. Please remove this note.

5. Main Components of the Flexi-grid Topology

This section describes the YANG module. It is specified in Section 8.

The description of the three main components, flexi-grid-node, flexi-grid-transponder and flexi-grid-link is provided below. flexi-grid-sliceable-transponders are also defined.

The syntax specification below uses the augmented Backus-Naur Form (BNF) as described in [RFC5234].

```
      <flexi-grid-node> ::= <config> <state>

         <flexi-grid-node>: This element designates a node in the
             network.

      <config> ::= <flexi-grid-node-attributes-config>

         <config>: Contains the configuration of a node.

      <flexi-grid-node-attributes-config> ::= <list-interface>
                                              <connectivity_matrix>

         <flexi-grid-node-attributes-config>: Contains all the
             attributes related to the node configuration, such as its
             interfaces or its management addresses.

      <list-interface> ::= <name> <port-number>
            <input-port> <output-port> <description>
            <interface-type>
            [<numbered-interface> / <unnumbered-interface>]

         <list-interface>: The list containing all the information of
             the interfaces.

         <name>: Determines the interface name.

         <port-number>: Port number of the interface.

         <input-port>: Boolean value that defines whether the interface
             is input or not.

         <output-port>: Boolean value that defines whether the interface
             is output or not.

         <description>: Description of the usage of the interface.
```

<interface-type>: Determines if the interface is numbered or unnumbered.

<numbered-interface> ::= <n-i-ip-address>

<numbered-interface>: An interface with its own IP address.

<n-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the IP address of the interface.

<unnumbered-interface> ::= <u-i-ip-address> <label>

<unnumbered-interface>: An interface that needs a label to be unique.

<u-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the node IP address, which with the label defines the interface.

<label>: Label that determines the interface, joint with the node IP address.

<connectivity-matrix> ::= <connections>

<connectivity-matrix>: Determines whether a connection port in/port out exists.

<connections> ::= <input-port-id> <output-port-id>

<flexi-grid-transponder> ::= <transponder-type> <config> <state>

<flexi-grid-transponder>: This item designates a transponder of a node.

<config> ::= <flexi-grid-transponder-attributes-config>

<config>: Contains the configuration of a transponder.

<flexi-grid-transponder-attributes-config> ::=
<available-operational-mode> <operational-mode>

<flexi-grid-transponder-attributes>: Contains all the attributes related to the transponder.

<available-operational-mode>: It provides a list of the operational modes available at this transponder.

```
         <operational-mode>: Determines the type of operational
             mode in use.

      <state> ::= <flexi-grid-transponder-attributes-config>
                  <flexi-grid-transponder-attributes-state>

         <state>: Contains the state of a transponder.

         <flexi-grid-transponder-attributes-config>: See above.

         <flexi-grid-transponder-attributes-state>: Contains the
             state of a transponder.

      <flexi-grid-link> ::= <config> <state>

         <flexi-grid-link>: This element describes all the
             information of a link.

      <config> ::= <flexi-grid-link-attributes-config>

         <config>: Contains the configuration of a link.

      <flexi-grid-link-attributes-config> ::= <technology-type>
                <available-label-flexi-grid> <N-max> <base-frequency>
                <nominal-central-frequency-granularity>
                <slot-width-granularity>

         <flexi-grid-link-attributes>: Contains all the attributes
             related to the link, such as its unique id, its N value,
             its latency, etc.

         <link-id>: Unique id of the link.

         <available-label-flexi-grid>: Array of bits that determines,
             with each bit, the availability of each interface for
             flexi-grid technology.

         <N-max>: The max value of N in this link, being N the number
             of slots.

         <base-frequency>: The default central frequency used in the
             link.

         <nominal-central-frequency-granularity>: It is the spacing
             between allowed nominal central frequencies and it is set
             to 6.25 GHz (note: sometimes referred to as 0.00625 THz).

         <slot-width-granularity>: 12.5 GHz, as defined in G.694.1.
```

```
<state> ::= <flexi-grid-link-attributes-config>
            <flexi-grid-link-attributes-state>

   <state>: Contains the state of a link.

   <flexi-grid-link-attributes-config>: See above.

   <flexi-grid-link-attributes-state>: Contains all the
       information related to the state of a link.

<flexi-grid-transponder> ::= <transponder-type> <config> <state>

   <flexi-grid-transponder>: This item designates a transponder
       of a node.

<config> ::= <flexi-grid-transponder-attributes-config>

   <config>: Contains the configuration of a transponder.

<flexi-grid-transponder-attributes-config> ::=
          <available-operational-mode> <operational-mode>

   <flexi-grid-transponder-attributes>: Contains all the
       attributes related to the transponder.

   <available-operational-mode>: It provides a list of the
       operational modes available at this transponder.

   <operational-mode>: Determines the type of operational
       mode in use.

<state> ::= <flexi-grid-transponder-attributes-config>
            <flexi-grid-transponder-attributes-state>

   <state>: Contains the state of a transponder.

   <flexi-grid-transponder-attributes-config>: See above.

   <flexi-grid-transponder-attributes-state>: Contains the
       state of a transponder.

<flexi-grid-link> ::= <config> <state>

   <flexi-grid-link>: This element describes all the information
       of a link.

<config> ::= <flexi-grid-link-attributes-config>
```

<config>: Contains the configuration of a link.

```
<flexi-grid-link-attributes-config> ::= <technology-type>
        <available-label-flexi-grid> <N-max> <base-frequency>
        <nominal-central-frequency-granularity>
        <slot-width-granularity>
```

<flexi-grid-link-attributes>: Contains all the attributes related to the link, such as its unique id, its N value, its latency, etc.

<link-id>: Unique id of the link.

<available-label-flexi-grid>: Array of bits that determines, with each bit, the availability of each interface for flexi-grid technology.

<N-max>: The max value of N in this link, being N the number of slots.

<base-frequency>: The default central frequency used in the link.

<nominal-central-frequency-granularity>: It is the spacing between allowed nominal central frequencies and it is set to 6.25 GHz (note: sometimes referred to as 0.00625 THz).

<slot-width-granularity>: 12.5 GHz, as defined in G.694.1.

```
<state> ::= <flexi-grid-link-attributes-config>
            <flexi-grid-link-attributes-state>
```

<state>: Contains the state of a link.

<flexi-grid-link-attributes-config>: See above.

<flexi-grid-link-attributes-state>: Contains all the information related to the state of a link.

```
<flexi-grid-transponder> ::= <transponder-type> <config> <state>
```

<flexi-grid-transponder>: This item designates a transponder of a node.

```
<config> ::= <flexi-grid-transponder-attributes-config>
```

<config>: Contains the configuration of a transponder.

```
<flexi-grid-transponder-attributes-config> ::=
          <available-operational-mode> <operational-mode>

   <flexi-grid-transponder-attributes>: Contains all the
       attributes related to the transponder.

   <available-operational-mode>: It provides a list of the
       operational modes available at this transponder.

   <operational-mode>: Determines the type of operational mode
       in use.

<state> ::= <flexi-grid-transponder-attributes-config>
            <flexi-grid-transponder-attributes-state>

   <state>: Contains the state of a transponder.

   <flexi-grid-transponder-attributes-config>: See above.

   <flexi-grid-transponder-attributes-state>: Contains the
       state of a transponder.

<flexi-grid-link> ::= <config> <state>

   <flexi-grid-link>: This element describes all the information
       of a link.

<config> ::= <flexi-grid-link-attributes-config>

   <config>: Contains the configuration of a link.

<flexi-grid-link-attributes-config> ::= <technology-type>
          <available-label-flexi-grid> <N-max> <base-frequency>
          <nominal-central-frequency-granularity>
          <slot-width-granularity>

   <flexi-grid-link-attributes>: Contains all the attributes
       related to the link, such as its unique id, its N value,
       its latency, etc.

   <link-id>: Unique id of the link.

   <available-label-flexi-grid>: Array of bits that determines,
       with each bit, the availability of each interface for
       flexi-grid technology.

   <N-max>: The max value of N in this link, being N the number
       of slots.
```

<base-frequency>: The default central frequency used in the link.

<nominal-central-frequency-granularity>: It is the spacing between allowed nominal central frequencies and it is set to 6.25 GHz (note: sometimes referred to as 0.00625 THz).

<slot-width-granularity>: 12.5 GHz, as defined in G.694.1.

```
<state> ::= <flexi-grid-link-attributes-config>
            <flexi-grid-link-attributes-state>
```

<state>: Contains the state of a link.

<flexi-grid-link-attributes-config>: See above.

<flexi-grid-link-attributes-state>: Contains all the information related to the state of a link.

6. Example of Use

In order to explain how this model is used, we provide the following example. An optical network usually has multiple transponders, switches (nodes) and links between them. Figure 1 shows a simple topology, where two physical paths interconnect two optical transponders.

```
                                   Media channel
               <====================================================>
                                      Path x
               <---------------------------------------------------->
                        +----------+           +----------+
                 Link 1 |Flexi-grid|  Link 2   |Flexi-grid| Link 3
                   .--->|   node   |<--------->|   node   |<---.
                   |    |    B     |           |     C    |    |
                   |    +----------+           +----------+    |
                   v                                           v
                /-----------\                           /-----------\
               / Flexi-grid  \                         / Flexi-grid  \
               | transponder |                         | transponder |
               \      A      /                         \      E      /
                \-----------/                           \-----------/
                     ^                                       ^
                     |               +----------+            |
                     |    Link 4     |Flexi-grid|   Link 5   |
                     '-------------->|   node   |<-----------'
                                     |    D     |
                                     +----------+
               <---------------------------------------------------->
                                      Path y
```

Figure 3: Topology Example

In order to configure a media channel to interconnect transponders A and E, first of all we have to populate the flexi-grid topology YANG model with all elements in the network:

- o We define the transponders A and E, including their FEC type, if enabled, and modulation type. We also provide node identifiers and addresses for the transponders, as well as interfaces included in the transponders. Sliceable transponders can also be defined if needed.

- o We do the same for the nodes B, C and D, providing their identifiers, addresses and interfaces, as well as the internal connectivity matrix between interfaces.

- o Then, we also define the links 1 to 5 that interconnect nodes and transponders, indicating which flexi-grid labels are available.

- o Other information, such as the slot frequency and granularity are also provided.

o Next, we can configure the media channel from the information we have stored in the flexi-grid TED, by querying which elements are available, and planning the resources that have to be provided on each situation. Note that every element in the flexi-grid TED has a reference, and this is the way in which they are called in the media channel. We refer to [I-D.ietf-ccamp-flexigrid-media-channel-yang] to complete this example.

7. YANG Model (Tree Structure) for Flexi-grid topology

```
module: ietf-flexi-grid-topology
  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw flexi-grid-topology!
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:te-node-attributes:
    +--rw flexi-grid-node!
  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
    +--rw flexi-grid
       +--rw slot-width-granularity?   identityref
       +--rw min-slot-width-factor?    uint16
       +--rw max-slot-width-factor?    uint16
  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
    +--rw flexi-grid
       +--rw slot-width-granularity?   identityref
       +--rw min-slot-width-factor?    uint16
       +--rw max-slot-width-factor?    uint16
  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
    +--rw flexi-grid
       +--rw slot-width-granularity?   identityref
       +--rw min-slot-width-factor?    uint16
       +--rw max-slot-width-factor?    uint16
  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
       +--ro flexi-grid
          +--ro slot-width-granularity?   identityref
          +--ro min-slot-width-factor?    uint16
          +--ro max-slot-width-factor?    uint16
     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
       +--ro flexi-grid
          +--ro slot-width-granularity?   identityref
          +--ro min-slot-width-factor?    uint16
          +--ro max-slot-width-factor?    uint16
     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
       +--ro flexi-grid
          +--ro slot-width-granularity?   identityref
          +--ro min-slot-width-factor?    uint16
          +--ro max-slot-width-factor?    uint16
     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
       +--rw flexi-grid
          +--rw slot-width-granularity?   identityref
          +--rw min-slot-width-factor?    uint16
          +--rw max-slot-width-factor?    uint16
     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
       +--rw flexi-grid
          +--rw slot-width-granularity?   identityref
          +--rw min-slot-width-factor?    uint16
```

```
          +--rw max-slot-width-factor?    uint16
     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
       +--rw flexi-grid
          +--rw slot-width-granularity?   identityref
          +--rw min-slot-width-factor?    uint16
          +--rw max-slot-width-factor?    uint16
     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
       +--ro flexi-grid
          +--ro slot-width-granularity?   identityref
          +--ro min-slot-width-factor?    uint16
          +--ro max-slot-width-factor?    uint16
     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
       +--rw flexi-grid
          +--rw slot-width-granularity?   identityref
          +--rw min-slot-width-factor?    uint16
          +--rw max-slot-width-factor?    uint16
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?             l0-types:flexi-n
             |  +--rw flexi-m?             l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?             l0-types:flexi-n
             |  +--rw flexi-m?             l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?             l0-types:flexi-n
             |  +--rw flexi-m?             l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
```

```
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 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/tet:label-start/tet:te-label
```

```
              /tet:technology:
        +--:(flexi-grid)
           +--rw flexi-n?   l0-types:flexi-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:
        +--:(flexi-grid)
           +--rw flexi-n?   l0-types:flexi-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:
        +--:(flexi-grid)
           +--rw flexi-grid-channel-spacing?   identityref
           +--rw flexi-n-step?                 uint8
    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:
        +--:(flexi-grid)
           +--rw (single-or-super-channel)?
              +--:(single)
              |  +--rw flexi-n?              l0-types:flexi-n
              |  +--rw flexi-m?              l0-types:flexi-m
              +--:(super)
                 +--rw subcarrier-flexi-n* [flexi-n]
                    +--rw flexi-n    l0-types:flexi-n
                    +--rw flexi-m?   l0-types:flexi-m
    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:
        +--:(flexi-grid)
           +--rw (single-or-super-channel)?
              +--:(single)
              |  +--rw flexi-n?              l0-types:flexi-n
              |  +--rw flexi-m?              l0-types:flexi-m
              +--:(super)
                 +--rw subcarrier-flexi-n* [flexi-n]
                    +--rw flexi-n    l0-types:flexi-n
                    +--rw flexi-m?   l0-types:flexi-m
    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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
```

```
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-grid-channel-spacing?   identityref
          +--ro flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?             l0-types:flexi-n
             |  +--ro flexi-m?             l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?             l0-types:flexi-n
             |  +--ro flexi-m?             l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
```

```
         +--ro (single-or-super-channel)?
            +--:(single)
            |  +--ro flexi-n?              l0-types:flexi-n
            |  +--ro flexi-m?              l0-types:flexi-m
            +--:(super)
               +--ro subcarrier-flexi-n* [flexi-n]
                  +--ro flexi-n    l0-types:flexi-n
                  +--ro flexi-m?   l0-types:flexi-m
  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:
    +--:(flexi-grid)
       +--ro (single-or-super-channel)?
          +--:(single)
          |  +--ro flexi-n?              l0-types:flexi-n
          |  +--ro flexi-m?              l0-types:flexi-m
          +--:(super)
             +--ro subcarrier-flexi-n* [flexi-n]
                +--ro flexi-n    l0-types:flexi-n
                +--ro flexi-m?   l0-types:flexi-m
  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:
    +--:(flexi-grid)
       +--ro (single-or-super-channel)?
          +--:(single)
          |  +--ro flexi-n?              l0-types:flexi-n
          |  +--ro flexi-m?              l0-types:flexi-m
          +--:(super)
             +--ro subcarrier-flexi-n* [flexi-n]
                +--ro flexi-n    l0-types:flexi-n
                +--ro flexi-m?   l0-types:flexi-m
  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:
    +--:(flexi-grid)
       +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-grid-channel-spacing?   identityref
          +--ro flexi-n-step?                 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/tet:label-start/tet:te-label
               /tet:technology:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-grid-channel-spacing?   identityref
          +--ro flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
    +--:(flexi-grid)
       +--ro (single-or-super-channel)?
          +--:(single)
          |  +--ro flexi-n?              l0-types:flexi-n
          |  +--ro flexi-m?              l0-types:flexi-m
          +--:(super)
             +--ro subcarrier-flexi-n* [flexi-n]
                +--ro flexi-n    l0-types:flexi-n
                +--ro flexi-m?   l0-types:flexi-m
  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:
    +--:(flexi-grid)
       +--ro (single-or-super-channel)?
          +--:(single)
          |  +--ro flexi-n?              l0-types:flexi-n
          |  +--ro flexi-m?              l0-types:flexi-m
          +--:(super)
             +--ro subcarrier-flexi-n* [flexi-n]
                +--ro flexi-n    l0-types:flexi-n
                +--ro flexi-m?   l0-types:flexi-m
  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:
    +--:(flexi-grid)
       +--ro (single-or-super-channel)?
          +--:(single)
          |  +--ro flexi-n?              l0-types:flexi-n
          |  +--ro flexi-m?              l0-types:flexi-m
          +--:(super)
             +--ro subcarrier-flexi-n* [flexi-n]
                +--ro flexi-n    l0-types:flexi-n
                +--ro flexi-m?   l0-types:flexi-m
  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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
```

```
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
```

```
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
```

```
                  +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--ro (single-or-super-channel)?
             +--:(single)
             |  +--ro flexi-n?              l0-types:flexi-n
             |  +--ro flexi-m?              l0-types:flexi-m
             +--:(super)
                +--ro subcarrier-flexi-n* [flexi-n]
                   +--ro flexi-n    l0-types:flexi-n
                   +--ro flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?              l0-types:flexi-n
             |  +--rw flexi-m?              l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--ro flexi-grid-channel-spacing?   identityref
          +--ro flexi-n-step?                 uint8
     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:
       +--:(flexi-grid)
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?             l0-types:flexi-n
             |  +--rw flexi-m?             l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
```

```
          +--rw (single-or-super-channel)?
             +--:(single)
             |  +--rw flexi-n?             l0-types:flexi-n
             |  +--rw flexi-m?             l0-types:flexi-m
             +--:(super)
                +--rw subcarrier-flexi-n* [flexi-n]
                   +--rw flexi-n    l0-types:flexi-n
                   +--rw flexi-m?   l0-types:flexi-m
     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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-n?   l0-types:flexi-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:
       +--:(flexi-grid)
          +--rw flexi-grid-channel-spacing?   identityref
          +--rw flexi-n-step?                 uint8
```

8. The YANG Code for Flexi-grid topology

```
   <CODE BEGINS> file "ietf-flexi-grid-topology@2020-09-21.yang"
    module ietf-flexi-grid-topology {
      yang-version 1.1;
      namespace "urn:ietf:params:xml:ns:yang:ietf-flexi-grid-topology";
      prefix "flexi-grid";

      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: Jorge E. Lopez de Vergara
                 <mailtojorge.lopez_vergara@uam.es>
         Editor: Daniel Perdices
                 <mailto:daniel.perdices@naudit.es>
         Editor: Haomian Zheng
                 <mailto:zhenghaomian@huawei.com>
         Editor: Daniel King
                 <mailto:d.king@lancaster.ac.uk>
         Editor: Young Lee
                 <mailto:younglee.tx@gmail.com>";

      description
        "This module defines a model for flexi-grid topology.
         Copyright (c) 2020 IETF Trust and the persons identified
         as authors of the code.  All rights reserved.
         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
         (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 2020-09-21 {
        description
          "Initial Version";
        reference
          "RFC XXXX: A Yang Data Model for flexi-grid 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 Flexi-grid topology type.";
           container flexi-grid-topology {
             presence
               "Its presence identifies the Flexi-grid topology type.";
             description
               "Introduce new network type for Flexi-grid 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/flexi-grid:flexi-grid-topology" {
          description
          "Augmentation parameters apply only for networks with
           Flexi-grid topology type.";
        }
        description "Augment TE node attributes.";
        container flexi-grid-node {
          presence "The TE node is a Flexi-grid node.";
          description "Flexi-grid node attributes";
        }
      }

      /*
       * 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/"
```

```
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the TE node
           connectivity matrices.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the source LTP
           of the connectivity matrix entry.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the destination LTP
           of the connectivity matrix entry.";
        uses l0-types:flexi-grid-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/"
```

```
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the TE node
           connectivity matrices information source.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the source LTP
           of the connectivity matrix entry information source.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the destination LTP
           of the connectivity matrix entry information source.";
        uses l0-types:flexi-grid-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/"
```

```
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the TTP
           Local Link Connectivities.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the TTP
           Local Link Connectivity entry.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range information for the TE link.";
        uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
```

```
           "Augmentation parameters apply only for networks with
            Flexi-grid topology type.";
       }
       description
         "Augment TE label range information for the TE link
          information source.";
       uses l0-types:flexi-grid-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:flexi-grid-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/"
          + "flexi-grid:flexi-grid-topology" {
         description
           "Augmentation parameters apply only for networks with
            Flexi-grid topology type.";
       }
       description
         "Augment TE label range start for the TE node
          connectivity matrices";
       case flexi-grid {
         uses l0-types:flexi-grid-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/"
          + "flexi-grid:flexi-grid-topology" {
```

```
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TE node
           connectivity matrices";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the TE node
           connectivity matrices";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path of the
           TE node connectivity matrices";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
            + "flexi-grid:flexi-grid-topology" {
           description
             "Augmentation parameters apply only for networks with
              Flexi-grid topology type.";
         }
         description
           "Augment TE label hop for the underlay backup path of the
            TE node connectivity matrices";
         case flexi-grid {
           uses l0-types:flexi-grid-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/"
            + "flexi-grid:flexi-grid-topology" {
           description
             "Augmentation parameters apply only for networks with
              Flexi-grid topology type.";
         }
         description
           "Augment TE label hop for the explicit route objects excluded
            by the path computation of the TE node connectivity
            matrices";
         case flexi-grid {
           uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the explicit route objects included
           by the path computation of the TE node connectivity
           matrices";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the TE node connectivity matrices";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the source LTP
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the source LTP
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
```

```
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the source LTP
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the destination LTP
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the destination LTP
           of the connectivity matrix entry.";
        case flexi-grid {
```

```
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the destination LTP
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay backup path
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the explicit route objects excluded
           by the path computation of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the explicit route objects included
           by the path computation of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the connectivity matrix entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
```

```
        description
          "Augment TE label range start for the TE node connectivity
           matrices information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TE node connectivity
           matrices information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the TE node connectivity
           matrices information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path
           of the TE node connectivity matrices of the information
           source entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay backup path
           of the TE node connectivity matrices of the information
           source entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
         description
           "Augmentation parameters apply only for networks with
            Flexi-grid 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 flexi-grid {
         uses l0-types:flexi-grid-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/"
          + "flexi-grid:flexi-grid-topology" {
         description
           "Augmentation parameters apply only for networks with
            Flexi-grid 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 flexi-grid {
         uses l0-types:flexi-grid-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/"
          + "flexi-grid:flexi-grid-topology" {
         description
           "Augmentation parameters apply only for networks with
```

```
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the TE node connectivity matrices information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the source LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the source LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the source LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the destination LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the destination LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the destination LTP
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
```

```
        description
          "Augment TE label hop for the underlay primary path
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay backup path
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid 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 flexi-grid {
```

```
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid 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 flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the connectivity matrix entry information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the TTP
           Local Link Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TTP
           Local Link Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the TTP
           Local Link Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path
           of the TTP Local Link Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
```

```
            "Augment TE label hop for the underlay backup path
             of the TTP Local Link Connectivities.";
          case flexi-grid {
            uses l0-types:flexi-grid-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/"
             + "flexi-grid:flexi-grid-topology" {
            description
              "Augmentation parameters apply only for networks with
               Flexi-grid topology type.";
          }
          description
            "Augment TE label hop for the explicit route objects excluded
             by the path computation of the TTP Local Link
             Connectivities.";
          case flexi-grid {
            uses l0-types:flexi-grid-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/"
             + "flexi-grid:flexi-grid-topology" {
            description
              "Augmentation parameters apply only for networks with
               Flexi-grid topology type.";
          }
          description
            "Augment TE label hop for the explicit route objects included
```

```
           by the path computation of the TTP Local Link
           Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the TTP Local Link Connectivities.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the TTP
           Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TTP
           Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the TTP
           Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path
           of the TTP Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay backup path
           of the TTP Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
```

```
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid 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 flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid 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 flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
```

```
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the computed path route objects
           of the TTP Local Link Connectivity entry.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay primary path
           of the TE link.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label hop for the underlay backup path
           of the TE link.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the TE link.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TE link.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range step for the TE link.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range start for the TE link
           information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
        }
        description
          "Augment TE label range end for the TE link
           information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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/"
           + "flexi-grid:flexi-grid-topology" {
          description
            "Augmentation parameters apply only for networks with
             Flexi-grid topology type.";
```

```
        }
        description
          "Augment TE label range step for the TE link
           information source.";
        case flexi-grid {
          uses l0-types:flexi-grid-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 flexi-grid {
          uses l0-types:flexi-grid-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 flexi-grid {
          uses l0-types:flexi-grid-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 flexi-grid {
          uses l0-types:flexi-grid-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 flexi-grid {
          uses l0-types:flexi-grid-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 flexi-grid {
          uses l0-types:flexi-grid-label-step;
        }
      }
    }
    <CODE ENDS>
```

9. 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:

/nw:networks/nw:network/nw:network-types/tet:te-topology

/nw:networks/nw:network/nt:link/tet:te/tet:te-link-attributes

/nw:networks/nw:network/nw:node/nt:termination-point/tet:te

/nw:networks/nw:network/nw:node/tet:te/tet:te-node-attributes
/te-connectivity-matrices/te-connectivity-matrix/tet:path-
constraints/tet:te-bandwidth/tet:technology

/nw:networks/nw:network/nw:node/tet:te
/tet:tunnel-termination-point/tet:local-link-connectivities
/tet:label-restrictions/tet:label-restriction

10. IANA Considerations

IANA is requested to assigned a new URI from the "IETF XML Registry" [RFC3688] as follows:

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

IANA is requested to assign a new YANG module name in the "YANG Module Names" registry [RFC6020] as follows:

Name: ietf-flexi-grid-topology
Namespace: urn:ietf:params:xml:ns:yang:ietf-flexi-grid-topology
Prefix: flexi-grid-topology
Reference: [This.I-D]

11. Contributors

The model presented in this documentr was contributed to by more people than can be listed in the author list. Additional contributors include:

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12. Acknowledgments

The work presented in this document has been partially funded by the European Commission under the project H2020 METRO-HAUL (Metro High bandwidth, 5G Application-aware optical network, with edge storage, compUte and low Latency), Grant Agreement number: 761727, and by the Spanish Ministry of Economy and Competitiveness under the project TRAFICA, MINECO/FEDER TEC2015-69417-C2-1-R.

Thanks to Adrian Farrel for reviewing this document and assisting with conversion to XML.

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September 19, 2020

A YANG Data Model for L1 Connectivity Service Model (L1CSM)
draft-ietf-ccamp-l1csm-yang-12

Abstract

This document provides a YANG data model for Layer 1 Connectivity Service Model (L1CSM). The intent of this document is to provide a Layer 1 service model exploiting YANG data model, which can be utilized by a customer network controller to initiate a service request connectivity as well as retrieving service states toward a Layer 1 network controller communicating with its customer network controller. This YANG model is NMDA-compliant.

Status of This Memo

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Table of Contents

1. Introduction

This document provides a YANG data model for L1VPN Connectivity Service Model (L1CSM) which can be classified as Network Service YANG module per [RFC8199]. The intent of this document is to provide a transport service model exploiting YANG data model, which can be utilized by a client network controller to initiate a service request connectivity request as well as retrieving service states toward a transport network controller communicating with the client controller via a NETCONF [RFC8341] or a RESTCONF [RFC8040] interface.

[RFC4847] provides a framework and service level requirements for Layer 1 Virtual Private Networks (L1VPNs). It classifies service models as management-based service model, signaling-based service model (Basic Mode) and signaling and routing service model (Enhanced Mode).

In the management-based service model, customer management systems and provider management systems communicate with each other. Customer management systems access provider management systems to request layer 1 connection setup/deletion between a pair of CEs. Customer management systems may obtain additional information, such as resource availability information and monitoring information, from provider management systems. There is no control message exchange between a CE and PE.

In the signaling-based service model (Basic Model), the CE-PE interface's functional repertoire is limited to path setup signaling only. In the Signaling and routing service model (Enhanced Mode), the CE-PE interface provides the signaling capabilities as in the Basic Mode, plus permits limited exchange of information between the control planes of the provider and the customer to help such functions as discovery of customer network routing information (i.e., reachability or TE information in remote customer sites), or parameters of the part of the provider's network dedicated to the customer.

The primary focus of this document is to describe L1CS YANG model required for the instantiation of point-to-point L1VPN service. A L1VPN is a service offered by a core layer 1 network to provide layer 1 connectivity between two or more customer sites where the customer has some control over the establishment and type of the connectivity.

The data model presented in Section 3 is in consistent with [MEF63]. The data model includes configuration and state data according to the new Network Management Datastore Architecture [RFC8342].

1.1. Deployment Scenarios

Figure 1 depicts a deployment scenario of the L1VPN SDN control-based service model for an external customer instantiating L1 point-to-point connectivity to the provider.

```
                             +------------+
                             |  Customer  |
                             |   Service  |
                             |Orchestrator|
                             +------------+
                                    |
                      .. .. .. .. ..|.. .. .. .. .. ..
                     :              |                 :
                     :     +--------------------+     :
                     :     |                    |     :
                     :     |    +----------+    |     :
                     :     |    | Network  |    |     :
                     :     |    |   SDN    |    |     :
                     :     |    |Controller|    |     :
                     :     |    |/NMS/EMS  |    |     :
                     :     |    +----------+    |     :
                     :     |                    |     :
                     :     |                    |     :
           +----+    :   +----+    +----+    +----+   :   +----+
           | CE |----:---| PE |----| P  |----| PE |---:---| CE |
           +----+    :   +----+    +----+    +----+   :   +----+
                     :     |                    |     :
                     :     |                    |     :
                     :     +--------------------+     :
                     :     |                    |     :
                     :     |<-Provider network->|     :

                 Customer                          Customer
                 Interface                         Interface
```

Figure 1: L1VPN SDN Controller/EMS/NMS-Based Service Model: External Customer

With this scenario, the customer service orchestrator interfaces with the network SDN controller of the provider using Customer Service Model as defined in [RFC8309].

Figure 2 depicts another deployment scenario for internal customer (e.g., higher-layer service management department(s)) interfacing the layer 1 transport network department. With this scenario, a multi-service backbone is characterized such that each service department of a provider (e.g., L2/3 services) that receives the same provider's L1VPN service provides a different kind of higher-layer service. The customer receiving the L1VPN service (i.e., each service department) can offer its own services, whose payloads can be any layer (e.g., ATM, IP, TDM). The layer 1 transport network and each service network belong to the same organization, but may be managed separately. The Service SDN Controller is the control/management entity owned by higher-layer service department (e.g., L2/3 VPN) whereas the Network SDN Controller is the control/management entity responsible for Layer 1 connectivity service. The CEs in Figure 2 are L2/3 devices that interface with L1 PE devices.

```
                                   +----------+
                                   | Service  |
                                   |   SDN    |
                                   |Controller|
                                   |/EMS/NMS  |
                                   | for L2/3 |
                                   +----------+
                                        |
                                        |
                                        |
                           +--------------------+
                           |                    |
                           |    +----------+    |
                           |    | Network  |    |
                           |    |   SDN    |    |
                           |    |Controller|    |
                           |    |/EMS/NMS  |    |
                           |    | for L1VPN|    |
                           |    +----------+    |
                           |                    |
                           |                    |
           +----+        +----+    +----+    +----+      +----+
           | CE |--------| PE |----| P  |----| PE |------| CE |
           +----+        +----+    +----+    +----+      +----+
              |            |                    |          |
              |            |                    |          |
              |            +--------------------+          |
              |            |                    |          |
              |            |<------------------>|          |
              |               Provider Network             |
              |                  For Layer 1               |
              |<------------------------------------------>|
                             Provider Network for L2/3
```

Figure 2: L1VPN SDN Controller/EMS/NMS-Based Service Model: Internal Customer

The benefit is that the same layer 1 transport network resources are shared by multiple services. A large capacity backbone network (data plane) can be built economically by having the resources shared by multiple services usually with flexibility to modify topologies, while separating the control functions for each service department. Thus, each customer can select a specific set of features that are needed to provide their own service [RFC4847].

1.2. Terminology

Refer to [RFC4847] and [RFC5253] for the key terms used in this document.

The following terms are defined in [RFC7950] and are not redefined here:

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

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

- configuration data
- state data

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

1.3. Tree Diagram

A simplified graphical representation of the data model is used in Section 3 of this this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

1.4. 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. The module ietf-layer1-types specified in [I-D.ietf-ccamp-layer1-types] and ietf-yang-types specified in [RFC6991] are imported in this module.

Prefix	YANG module	Reference
l1csm	ietf-l1csm	[RFC XXXX]
l1-types	ietf-layer1-types	[I-D.ietf-ccamp-layer1-types]
yang	ietf-yang-types	[RFC6991]

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

2. Definitions

L1VC Layer 1 Virtual Connection

SLS Service Level Specification

UNI User Network Interface

PE Provider Edge

CE Customer Edge

EP End Point

P Protocol

C Coding

O Optical Interface

3. L1CSM YANG Model (Tree Structure)

```
   module: ietf-l1csm
     +--rw l1-connectivity
        +--rw access
        |  +--rw unis
        |     +--rw uni* [id]
        |        +--rw id                    string
        |        +--rw protocol?             identityref
        |        +--rw coding?               identityref
        |        +--rw optical-interface?   identityref
        +--rw services
           +--rw service* [service-id]
              +--rw service-id            string
              +--rw endpoint-1
              |  +--rw id     string
              |  +--rw uni
              |          -> /l1-connectivity/access/unis/uni/id
              +--rw endpoint-2
              |  +--rw id     string
              |  +--rw uni
              |          -> /l1-connectivity/access/unis/uni/id
              +--rw start-time?           yang:date-and-time
              +--rw time-interval?        int32
              +--rw performance-metric*   identityref
```

4. L1CSM YANG Code

```
  <CODE BEGINS>file "ietf-l1csm@2020-03-09.yang"
  module ietf-l1csm {
    yang-version 1.1;
    namespace "urn:ietf:params:xml:ns:yang:ietf-l1csm";
    prefix "l1csm";

    import ietf-yang-types {
      prefix "yang";
    }

    import ietf-layer1-types {
      prefix "l1-types";
    }

    organization
      "Internet Engineering Task Force (IETF) CCAMP WG";

    contact
```

```
      "Editor: Y. Lee (younglee.tx@gmail.com)
       Editor: K. Lee (kwangkoog.lee@kt.com)
       Editor: H. Zheng (zhenghaomian@huawei.com)
       Editor: D. Dhody (dhruv.ietf@gmail.com)
       Editor: O. G. de-Dios (oscar.gonzalezdedios@telefonica.com)
       Editor: D. Ceccarelli (daniele.ceccarelli@ericsson.com)";

    description
      "This module describes L1 connectivity service based on MEF 63:
       Subscriber Layer 1 Service Attribute Technical Specification.
       Refer to MEF 63 for all terms and the original references
       used in the module.

       Copyright (c) 2020 IETF Trust and the persons identified as
       authors of the code.  All rights reserved.
       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
       (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 "2020-03-09" {
         description "Initial revision.";
         reference "RFC XXXX: A Yang Data Model for L1 Connectivity
                    Service Model (L1CSM)";
    // Note: The RFC Editor will replace XXXX with the number
    // assigned to the RFC once this document becomes an RFC.
    }

      grouping protocol-coding-optical-interface {
       description
        "describes <p,c,o> where p:protocol type; c:coding
         function; o:optical interface function";
        reference "MEF 63";
        leaf protocol {
          type identityref {
            base "l1-types:client-signal";
          }
          description
            "List of physical layer L1VC client protocol";

        }
        leaf coding {
           type identityref {
```

```
             base "l1-types:coding-func";
           }
           description "coding function";
        }

         leaf optical-interface {
           type identityref {
             base "l1-types:optical-interface-func";
           }
           description "optical-interface-function";
        }

       }

    grouping subscriber-l1vc-sls-service-attribute {
       description
        "The value of the Subscriber L1VC SLS (Service Level
          Specification) Service Attribute";
        reference "MEF 63";

        leaf start-time {
          type yang:date-and-time;
          description "a time that represent the date and time
                       for the start of the SLS";
        }

        leaf time-interval {
          type int32;
          units seconds;
          description
            "a time interval (e.g., 2,419,200 seconds which is 28 days)
            that is used in conjunction wuth time-start to specify a
            contiguous sequence of time intervals T for determining
            when performance objectives are met.";
        }

        leaf-list performance-metric {
          type identityref {
            base "l1-types:service-performance-metric";
          }
          description "list of service performance metric.";
        }

    }

    grouping subscriber-l1vc-endpoint-attributes {
       description
        "subscriber layer 1 connection endpoint attributes";
```

```
        reference "MEF 63";

        container endpoint-1 {
          description "One end of UNI id's - string and id";
          leaf id {
            type string;
            mandatory true;
            description "subscriber end point ID of one end";
          }

          leaf uni {
            type leafref {
              path "/l1-connectivity/access/unis/uni/id";
            }
             mandatory true;
            description "this is one end of subscriber L1VC end point
             ID value = UNI-1";
          }
        }
        container endpoint-2 {
          description "One end of UNI id's - string and id";
          leaf id {
            type string;
             mandatory true;
            description "subscriber end point ID of the other end";
          }

          leaf uni {
            type leafref {
              path "/l1-connectivity/access/unis/uni/id";
            }
             mandatory true;
            description
               "this is one other end of subscriber L1VC end point
                ID value = UNI-2";
          }
        }
    }

    container l1-connectivity {
      description
        "serves as a top-level container for a list of layer 1
         connection services (l1cs)";

        container access {
          description "UNI configurations for access networks";

          container unis {
```

```
            description "the list of UNI's to be configured";

            list uni {
              key "id";
              description "UNI identifier";
                  leaf id {
                    type string;
                     description "the UNI id of UNI Service Attributes";
                  }

                 uses protocol-coding-optical-interface;
            }
          }
        }

         container services {
           description "L1VC services";
             list service {
               key "service-id";
               description
                 "an unique identifier of a subscriber L1VC service";

                 leaf service-id {
                   type string;
                       mandatory true;
                   description "a unique service identifier for
                      subscriber L1VC.";
                 }

                 uses subscriber-l1vc-endpoint-attributes;
                 uses subscriber-l1vc-sls-service-attribute;

             }//end of service list
         } //end of service container
    }//service top container
  }

  <CODE ENDS>
```

5. JSON Example

This section provides a JSON example of the YANG module described in Section 4. This example configures one L1VC service with two UNIs that describe the UNI endpoints. The service is configured with the starting time to be 06:06:09 on 2018-09-13 for the service life time of 2419200 seconds (which is corresponds to 28 days). In addition, the service is configured to collect one performance metric, One-way-Delay.


```
{
  "l1-connectivity": {
    "access": {
      "unis": {
        "uni": [
          {
            "id": "MTL-HQ-Node3-Slot2-Port1",
            "protocol": "ETH-10GigE_LAN ",
            "coding": "ETH-10GR-PCS-49 ",
            "optical_interface": "LR-PMD-clause-52 "
          },
          {
            "id": "MTL-STL-Node5-Slot4-Port3",
            "protocol": "ETH-10GigE_LAN ",
            "coding": "ETH-10GR-PCS-49 ",
            "optical_interface": "ER-PMD-clause-52 "
          }
        ]
      },
    },
    "services": {
      "service": [
        {
          "service-id": "Sub-L1VC-1867-LT-MEGAMART",
          "endpoint-1":
            {
              "id": "MTL-HQ_1867-MEGAMART",
              "uni": "MTL-HQ-Node3-Slot2-Port1"
            },
          "endpoint-2":
            {
              "id": "MTL-STL_1867-MEGAMART",
              "uni": "MTL-STL-Node5-Slot4-Port3"
            },
          "start-time": "2018-09-13T06:06:09Z",
          "time-interval": 2419200,
          "performance-metric": "One-way-Delay "
        }
      ]
    },
}
```

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.

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.

These are the subtrees and data nodes and their sensitivity/ vulnerability:

unis:

- id

Service:

- service-id

- endpoint-1

- endpoint-2

- start-time

- time-interval

- performance-metric

The security considerations spelled out in the YANG 1.1 specification [RFC7950] apply for this document as well.

7. IANA Considerations

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

URI: urn:ietf:params:xml:ns:yang:ietf-l1csm
Registrant Contact: The IESG
XML: N/A; the requested URI is an XML namespace.

This document registers following YANG modules in the YANG Module Names registry [RFC7950].

```
name:         ietf-l1csm
namespace:    urn:ietf:params:xml:ns:yang:ietf-l1csm
prefix:       l1csm
reference:    RFC XXXX
```

8. Acknowledgements

The authors would like to thank Tom Petch for his helpful comments and valuable contributions and Robert Wilton for his review that improved the model significantly.

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Intended status: Standards Track   Huawei Technologies
Expires: March 25, 2021   September 21, 2020

A YANG Data Model for Layer 1 Types
draft-ietf-ccamp-layer1-types-07

Abstract

This document defines a collection of common data types and groupings in the YANG data modeling language for use with layer 1 networks. These derived common types and groupings are intended to be imported by modules that specify OTN networks, such as topology, tunnel, client signal adaptation and service.

Status of This Memo

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Table of Contents

1. Introduction

This document specifies common data types for use in YANG [RFC7950] data models of Layer 1 networks. The derived types and groupings are types applicable to modeling Traffic Engineering (TE) for Layer 1 networks.

The Optical Transport Networking, a typical Layer 1 network, is specified in [RFC7062]. The corresponding routing and signaling protocol are specified in [RFC7138] and [RFC7139]. The types and groupings defined in this document are consistent to those documents, and can be imported into other Layer 1 data models, including but not limited to, [I-D.ietf-ccamp-otn-topo-yang], [I-D.ietf-ccamp-otn-tunnel-model], [I-D.ietf-ccamp-client-signal-yang] and [I-D.ietf-ccamp-l1csm-yang].

The data model in this draft only defines groupings, typedef and identities. There is no configuration or state data as specified in the Network Management Datastore Architecture [RFC8342]. The document is consistent with other specifications, including [MEF63] for Layer 1 service attributes, [ITU-Tg709] and [ITU-Tgsup43] for OTN data plane definitions.

2. Terminology and Notations

Refer to [RFC7062] for the key terms used in this document. The terminology for describing YANG data models can be found in [RFC7950].

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.

Prefix	YANG module	Reference
l1-types	ietf-layer1-types	This Document

4. Layer 1 Types Overview

4.1. Relationship with other Modules

This document defines one YANG module for common Layer 1 types. The aim is to specify common Layer 1 TE types (i.e. typedef, identity, grouping) that can be imported by layer 1 specific technology, for example OTN, in its technology-specific modules, such as topology and tunnels. It is worth noting that the generic traffic-engineering (TE) types module is specified in [RFC8776] as ietf-te-types, and both YANG modules, ietf-te-types and ietf-layer1-types, will need importing when the OTN is configured. Generic attributes such as te-bandwidth and te-label, are specified in ietf-te-types in [RFC8776], while the OTN-specific attributes, such as odu-type, are specified in ietf-layer1-types in this document.

4.2. Content in Layer 1 Type Module

The module ietf-layer1-types contains the following YANG reusable types and groupings:

tributary-slot-granularity:

This specifies the granularity of the server layer ODU Link (HO ODUk or ODUCn) supporting a client layer ODU LSP (LO ODUj or ODUk, respectively). Three granularities, 1.25G/2.5G/5G, have been specified.

odu-type:

This specifies the type of ODUk LSP, including the types specified in [RFC7139] and [RFC7963].

client-signal:

This specifies the client signal types of OTN networks. The initial input was the G-PID specified in [RFC7139]. Identities for some of the categories of client signal types, including ETH, STM-n, OC [Telcordia] and Fiber Channel, have been specified.

otn-label-range-type:

The label range type of OTN is represented in one of two ways, tributary slots (TS) and tributary port number (TPN), as specified in [RFC7139]. Two representations are enumerated in the otn-label-range-type.

otn-link-bandwidth:

This grouping defines the link bandwidth information and could be used in OTN topology model for link bandwidth representation. All the bandwidth related sections in generic module, [RFC8776], need to be augmented with this grouping for the usage of Layer 1.

otn-path-bandwidth:

This grouping defines the path bandwidth information and could be used in OTN topology model for path bandwidth representation. All the bandwidth related sections in generic module, [RFC8776], need to be augmented with this grouping for the usage of Layer 1. This grouping is also applicable when setting up the OTN tunnel.

otn-label-range-info and otn-label-step:

These groupings are used to augment an OTN label with type, granularity, priority and ODU types.

otn-label-start-end and otn-label-hop:

These groupings are used to augment a label for an OTN link and path respectively.

optical-interface-func:

The optical interface function is specified in [MEF63]. This grouping describes the functionality which encodes bits for transmission and decodes bits upon reception.

service-performance-metric:

The service performance metric is a quantitative characterization of the quality of the delivery of Layer 1 characteristic information as experienced by the Layer 1 subscriber.

4.3. OTN Label and Label Range

As described in [RFC7139], the OTN label usually represents the Tributary Port Number (TPN) and the related set of Tributary Slots (TS) assigned to a client layer ODU LSP (LO ODUj or ODUk) on a given server layer ODU (HO-ODU or ODUCn, respectively) Link (e.g., ODU2 LSP over ODU3 Link). Some special OTN label values are also defined for an ODUk LSP being set up over an OTUk Link.

The same OTN label must be assigned to the same ODUk LSP at the two ends of an OTN Link.

As described in [RFC7139], TPN can be a number from 1 to 4095 and TS are numbered from 1 to 4095, although the actual maximum values depend on the type of server layer ODU. For example, a server layer ODU4 provides 80 time slots (numbered from 1 to 80) and the TPN values can be any number from 1 to 80.

The OTN Label Range represents the values for the TPN and TS that are available for ODUk LSPs to be setup over a given OTN Link.

The OTN Label Range is defined by the label-restriction list, defined in [RFC8776], which, for OTN, should be augmented using the otn-label-range-info grouping.

Each entry in the label-restriction list represents either the range of the available TPN values or the range of the available TS values: the range-type attribute in the otn-label-range-info grouping defines the type of range for each entry of the list.

Each entry of the label-restriction list, as defined in [RFC8776], defines a label-start, a label-end, a label-step and a range-bitmap. The label-start and label-end definitions for OTN should be augmented using the otn-label-start-end grouping. The label-step definition for OTN should be augmented using the otn-label-step grouping. It is expected that the otn-label-step will always be equal to its default value (i.e., 1), which is defined in [RFC8776].

As described in [RFC7139], in some cases, the TPN assignment rules are flexible (e.g., ODU4 Link) while in other cases the TPN assignment rules are fixed (e.g., ODU1 Link). In the former case, both TPN and TS ranges are reported, while in the latter case, the TPN range is not reported which indicates that the TPN shall be set equal to the TS number assigned to the ODUk LSP.

As described in [RFC7139], in some cases, the TPN assignment rules depends on the TS Granularity (e.g., ODU2 or ODU3 Links). Different entries in the label-restriction list will report different TPN ranges for each TS granularity supported by the link, as indicated by the tsg attribute in the otn-label-range-info grouping.

As described in [RFC7139], in some cases the TPN ranges are different for different types of ODUk LSPs. For example, on an ODU2 Link with 1.25G TS granularity, the TPN range is 1-4 for ODU1 but 1-8 for ODU0 and ODUflex. Different entries in the label-restriction list will report different TPN ranges for different set of ODUk types, as indicated by the odu-type-list in the otn-label-range-info grouping.

Appendix A provides some examples of how the TPN and TS label ranges described in Table 3 and Table 4 of [RFC7139] can be represented in YANG using the groupings defined in this document.

4.4. ODUflex

ODUflex is a type of ODU which has a flexible bit rate which is configured when setting up an ODUflex LSP.

[ITU-Tg709], defines six types of ODUflex: ODUflex(CBR), ODUflex(GFP), ODUflex(GFP,n,k), ODUflex(IMP), ODUflex(IMP,s) and ODUflex(FlexE-aware).

The main difference between these types of ODUflex is the formula used to calculate the nominal bit rate of the ODUflex, as described in Table 7-2 of [ITU-Tg709]. A YANG choice has been defined to describe these cases:

```
         +--rw (oduflex-type)?
            +--:(generic)
            |  +--rw nominal-bit-rate        uint64
            +--:(cbr)
            |  +--rw client-type             identityref
            +--:(gfp-n-k)
            |  +--rw gfp-n                   uint8
            |  +--rw gfp-k?                  l1-types:gfp-k
            +--:(flexe-client)
            |  +--rw flexe-client
            |          l1-types:flexe-client-rate
            +--:(flexe-aware)
            |  +--rw flexe-aware-n           uint16
            +--:(packet)
               +--rw opuflex-payload-rate    uint64
```

The 'generic' case has been added to allow the ODUflex nominal bit rate to be defined independently from the type of ODUflex. This could be useful for forward compatibility in the transit domain/nodes where the setup of ODUflex LSPs does not depend on the ODUflex type.

In order to simplify interoperability the 'generic' case should be used only when it is needed; the ODUflex type-specific case should be used whenever possible.

The 'cbr' case is used for Constant Bit Rate (CBR) client signals. The client-type indicates which CBR client signal is carried by the ODUflex and, implicitly, the client signal bit rate which is then used to calculate the ODUflex(CBR) nominal bit rate as described in Table 7-2 of [ITU-Tg709].

The 'gfp-n-k' case is used for GFP-F mapped client signals based on ODUk.ts and 'n' 1.25G tributary slots. 'gfp-k' defines the nominal bit-rate of the ODUk.ts which, together with the value of 'gfp-n', is used to calculated the ODUflex(GFP,n,k) nominal bit rate as described in Table 7-8 and Table L-7 of [ITU-Tg709] . With a few exceptions, shown in Table L-7 of [ITU-Tg709], the nominal bit-rate of the ODUk.ts could be inferred from the value of 'n', as shown in Table 7-8 of [ITU-Tg709] and therefore the 'gfp-k' is optional.

The 'flexe-client' case is used for Idle Mapping Procedure(IMP) mapped FlexE client signals, The 'flexe-client' represents the type of FlexE client carried by the ODUflex which implicitly defines the value of 's' used to calculate the ODUflex(s) nominal bit rate as described in Table 7-2 of [ITU-Tg709]. The '10G' and '40G' enumeration values are used for 10G and 40G FlexE clients to implicitly define the values of s=2 and s=8. For the 'n x 25G' FlexE Clients the value of 'n' is used to defines the value of s=5 x n.

The 'flexe-aware' case is used for FlexE-aware client signals. The flexe-aware-n represents the value n (n = n1 + n2 + ... + np) which is used to calculate the ODUflex(FlexE-aware) nominal bit rate as described in Table 7-2 of [ITU-Tg709].

The 'packet' case is used for both the GFP-F mapped client signals and the IMP mapped client signals. The opuflex-payload-rate is either the GFP-F encapsulated-packet client nominal bit rate or the 64b/66b encoded-packet client nominal bit rate. The calculation of ODUflex(GFP) nominal bit rate is defined in section 12.2.5 of [ITU-Tg709], and the calculation of ODUflex(IMP) nominal bit rate is defined in section 12.2.6 of [ITU-Tg709]. The same formula is used in both cases.

Section 5.1 and 5.2 of [RFC7139] defines two rules to compute the number of tributary slots to be allocated to ODUflex(CBR) and ODUflex(GFP) LSPs when carried over a HO-ODUk link. According to section 19.6 of [ITU-Tg709], the rules in section 5.2 apply only to ODUflex(GFP,n,k) while the rules defined in section 5.1 apply to any other ODUflex type, including, but not limited, to ODUflex(CBR). Section 20.5 of [ITU-Tg709] defines the rules for computing the number of tributary slots to be allocated to ODUflex LSPs when carried over an ODUCn link.

Following the [ITU-Tg709] definitions, the rules defined for ODUflex(GFP,n,k) are used only when the 'gfp-n-k' case is used. In all the other cases, including the (generic) case, the rules defined any other ODUflex type are used.

The number of available ODUs, defined for each ODUk type, including ODUflex, together with the number of available time-slots, reported as part of the OTN label range, provide sufficient information to infer the OTN link bandwidth availability for ODUflex LSPs. This information is independent of the ODUflex type.

4.4.1. Resizable ODUflex

Resizable ODUflex is a special type of ODUflex that supports the procedures defined in [ITU-Tg7044] for hitless resizing of the ODUflex nominal bit rate.

Two odu-type identities have been defined for ODUflex:

- o The ODUflex identity, which is used with any type of non-resizable ODUflex, as defined in Table 7-2 of [ITU-Tg709].

o The ODUflex-resizable identity, which is used only with resizable ODUflex(GFP,n,k).

These two identities are used to identify whether an ODUflex(GFP,n,k) LSP does or does support the [ITU-Tg7044] hitless resizing procedures. They also identify whether an OTN link only supports the setup of non-resizable ODUflex LSPs or also supports the setup of resizable ODUflex(GFP,n,k) LSP but with different capabilities (e.g., a lower number of LSPs).

5. YANG Code for Layer1 Types

```
<CODE BEGINS>file "ietf-layer1-types@2020-09-21.yang"
module ietf-layer1-types {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-layer1-types";
  prefix "l1-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>";

  description
    "This module defines Layer 1 types (typedef, identity,
      grouping). The model fully conforms to the Network Management
      Datastore Architecture (NMDA).
     Copyright (c) 2020 IETF Trust and the persons
     identified as authors of the code.  All rights reserved.
     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 "2020-09-21" {
    description
      "Initial Version";
    reference
```

```
         "RFC XXXX: A YANG Data Model for Layer 1 Types";
       // RFC Editor: replace XXXX with actual RFC number, update date
       // information and remove this note
     }

     typedef otn-tpn {
       type uint16 {
         range "1..4095";
       }
       description
         "Tributary Port Number for OTN. ";
       reference
         "RFC7139: GMPLS Signaling Extensions for Control of Evolving
          G.709 Optical Transport Networks.";
     }

     typedef otn-ts {
       type uint16 {
         range "1..4095";
       }
       description
         "Tributary Slot for OTN. ";
       reference
         "RFC7139: GMPLS Signaling Extensions for Control of Evolving
          G.709 Optical Transport Networks.";
     }

     typedef otn-label-range-type {
       type enumeration {
         enum trib-slot {
           description
             "Defines a range of OTN tributary slots. ";
         }
         enum trib-port {
           description
             "Defines a range of OTN tributary ports. ";
         }
       }
       description
         "Defines the type of OTN label range: TS or TPN. ";
     }

     typedef gfp-k {
       type enumeration {
         enum 2 {
           description
             "The ODU2.ts rate (1,249,177.230 kbit/s) is used
              to compute the rate of an ODUflex(GFP,n,2). ";
```

```
         }
         enum 3 {
           description
             "The ODU3.ts rate (1,254,470.354 kbit/s) is used
              to compute the rate of an ODUflex(GFP,n,3). ";
         }
         enum 4 {
           description
             "The ODU4.ts rate (1,301,467.133 kbit/s) is used
              to compute the rate of an ODUflex(GFP,n,4). ";
         }
       }
       description
         "The ODUk.ts used to compute the rate of an ODUflex(GFP,n,k)";
       reference
         "Table 7-8 and L-7 of G.709";
     }

     typedef flexe-client-rate {
       type union {
         type uint16;
         type enumeration {
           enum "10G" {
             description
               "Represents a 10G FlexE Client signal (s=2)";
           }
           enum "40G" {
             description
               "Represents a 40G FlexE Client signal (s=8)";
           }
         }
       }
       description
         "The FlexE Client signal rate (s x 5,156,250.000 kbit/s)
          used to compute the rate of an ODUflex(IMP, s).
          Valid values for s are s=2 (10G), s=4 (40G) and
          s=5 x n (n x 25G).
          In the first two cases an enumeration value
          (either 10G or 40G) is used, while in the latter case
          the value of n is used";
       reference
         "Table 7-2 of G.709";
     }

     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 tsg-5G {
       base tributary-slot-granularity;
       description
         "5G tributary slot granularity";
     }

     identity odu-type {
       description
         "Base identity for the type of ODU protocol.";
     }

     identity ODU0 {
       base odu-type;
       description
         "ODU0 protocol (1.24Gb/s). ";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODU1 {
       base odu-type;
       description
         "ODU1 protocol (2.49Gb/s).";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODU1e {
       base odu-type;
       description
         "ODU1e protocol (10.35Gb/s).";
       reference "RFC7963/ITU-T G.sup43";
     }
```

```
     identity ODU2 {
       base odu-type;
       description
         "ODU2 protocol (10.03Gb/s).";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODU2e {
       base odu-type;
       description
         "ODU2e protocol (10.39Gb/s).";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODU3 {
       base odu-type;
       description
         "ODU3 protocol (40.31Gb/s).";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODU3e1 {
       base odu-type;
       description
         "ODU3e1 protocol (41.77Gb/s).";
       reference "RFC7963/ITU-T G.sup43";
     }

     identity ODU3e2 {
       base odu-type;
       description
         "ODU3e2 protocol (41.78Gb/s).";
       reference "RFC7963/ITU-T G.sup43";
     }

     identity ODU4 {
       base odu-type;
       description
         "ODU4 protocol (104.79Gb/s).";
       reference "RFC7139/ITU-T G.709";
     }

     identity ODUflex {
       base odu-type;
       description
         "ODUflex protocol (flexible bit rate, not resizable).
          It can be used for any type of ODUflex, including
          ODUflex(CBR), ODUflex(GFP), ODUflex(GFP,n,k), ODUflex(IMP,s),
```

```
           ODUflex(IMP) and ODUflex(FlexE-aware).";
        reference "RFC7139/ITU-T G.709";
      }

      identity ODUflex-resizable {
        base odu-type;
        description
          "ODUflex protocol (flexible bit rate, resizable).
           It can only be used for ODUflex(GFP,n,k).";
        reference "RFC7139/ITU-T G.709 and ITU-T G.7044";
      }

      identity client-signal {
        description
          "Base identity from which specific client signals for the
           tunnel are derived";
      }

      identity ETH-1Gb {
        base client-signal;
        description
          "Client signal type of 1GbE";
        reference "RFC7139/ITU-T G.709";
      }

      identity ETH-10Gb-LAN {
        base client-signal;
        description
          "Client signal type of ETH-10Gb-LAN (10.3 Gb/s)";
        reference "RFC7139/ITU-T G.709/IEEE 802.3 Clause 49";
      }

      identity ETH-10Gb-WAN {
        base client-signal;
        description
          "Client signal type of ETH-10Gb-WAN (9.95 Gb/s)";
        reference "RFC7139/ITU-T G.709/IEEE 802.3 Clause 50";
      }

      identity ETH-40Gb {
        base client-signal;
        description
          "Client signal type of 40GbE";
        reference "RFC7139/ITU-T G.709";
      }
      identity ETH-100Gb {
        base client-signal;
        description
```

```
          "Client signal type of 100GbE";
        reference "RFC7139/ITU-T G.709";
      }

      identity STM-1 {
        base client-signal;
        description
          "Client signal type of STM-1";
        reference "RFC7139/ITU-T G.709";
      }

      identity STM-4 {
        base client-signal;
        description
          "Client signal type of STM-4";
        reference "RFC7139/ITU-T G.709";
      }

      identity STM-16 {
        base client-signal;
        description
          "Client signal type of STM-16";
        reference "RFC7139/ITU-T G.709";
      }

      identity STM-64 {
        base client-signal;
        description
          "Client signal type of STM-64";
        reference "RFC7139/ITU-T G.709";
      }

      identity STM-256 {
        base client-signal;
        description
          "Client signal type of STM-256";
        reference "RFC7139/ITU-T G.709";
      }

      identity OC-3 {
        base client-signal;
        description
          "Client signal type of OC3";
        reference "Telcordia GR-253-CORE";
      }
      identity OC-12 {
        base client-signal;
        description
```

```
          "Client signal type of OC12";
        reference "Telcordia GR-253-CORE";
      }

      identity OC-48 {
        base client-signal;
        description
          "Client signal type of OC48";
        reference "Telcordia GR-253-CORE";
      }

      identity OC-192 {
        base client-signal;
        description
          "Client signal type of OC192";
        reference "Telcordia GR-253-CORE";
      }

      identity OC-768 {
        base client-signal;
        description
          "Client signal type of OC768";
        reference "Telcordia GR-253-CORE";
      }

      identity FC-100 {
        base client-signal;
        description
          "Client signal type of Fibre Channel FC-100";
        reference "RFC4328/RFC7139";
      }

      identity FC-200 {
        base client-signal;
        description
          "Client signal type of Fibre Channel FC-200";
        reference "RFC4328/RFC7139";
      }

      identity FC-400 {
        base client-signal;
        description
          "Client signal type of Fibre Channel FC-400";
        reference "RFC4328/RFC7139";
      }
      identity FC-800 {
        base client-signal;
        description
```

```
         "Client signal type of Fibre Channel FC-800";
       reference "RFC4328/RFC7139";
     }

     identity FC-1200 {
       base client-signal;
       description
         "Client signal type of Fibre Channel FC-1200";
       reference "RFC4328/RFC7139";
     }

     identity FC-1600 {
       base client-signal;
       description
         "Client signal type of Fibre Channel FC-1600";
       reference "RFC4328/RFC7139";
     }

     identity FC-3200 {
       base client-signal;
       description
         "Client signal type of Fibre Channel FC-3200";
       reference "RFC4328/RFC7139";
     }

     identity FICON-4G {
       base client-signal;
       description
         "Client signal type of Fibre Connection 4G";
       reference "RFC4328/RFC7139";
     }

     identity FICON-8G {
       base client-signal;
       description
         "Client signal type of Fibre Connection 8G";
       reference "RFC4328/RFC7139";
     }

     identity coding-func {
       description
         "Base identity from which coding function is derived.";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity ETH-1000X {
       base "coding-func";
       description
```

```
         "PCS clause 36 coding function that corresponds to
          1000BASE-X";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity ETH-10GW {
       base "coding-func";
       description
         "PCS clause 49 and WIS clause 50 coding func that
          corresponds to 10GBASE-W (WAN PHY)";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity ETH-10GR {
       base "coding-func";
       description
         "PCS clause 49 coding function that corresponds to
          10GBASE-R (LAN PHY)";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity ETH-40GR {
       base "coding-func";
       description
         "PCS clause 82 coding function that corresponds to
          40GBASE-R";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity ETH-100GR {
       base "coding-func";
       description
         "PCS clause 82 coding function that corresponds to
          100GBASE-R";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity optical-interface-func {
       description
         "base identity from which optical-interface-function is
          derived.";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity SX-PMD-1000 {
       base "optical-interface-func";
       description
         "SX-PMD-clause-38 Optical Interface function for
```

```
         1000BASE-X PCS-36";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity LX-PMD-1000 {
       base "optical-interface-func";
       description
         "LX-PMD-clause-38 Optical Interface function for
          1000BASE-X PCS-36";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity LX10-PMD-1000 {
       base "optical-interface-func";
       description
         "LX10-PMD-clause-59 Optical Interface function for
          1000BASE-X PCS-36";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity BX10-PMD-1000 {
       base "optical-interface-func";
       description
         "BX10-PMD-clause-59 Optical Interface function for
          1000BASE-X PCS-36";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity LW-PMD-10G {
       base "optical-interface-func";
       description
         "LW-PMD-clause-52 Optical Interface function for
          10GBASE-W PCS-49-WIS-50";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity EW-PMD-10G {
       base "optical-interface-func";
       description
         "EW-PMD-clause-52 Optical Interface function for
          10GBASE-W PCS-49-WIS-50";
       reference "MEF63: Subscriber Layer 1 Service Attributes";
     }

     identity LR-PMD-10G {
       base "optical-interface-func";
       description
         "LR-PMD-clause-52 Optical Interface function for
```

```
         10GBASE-R PCS-49";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity ER-PMD-10G {
      base "optical-interface-func";
      description
        "ER-PMD-clause-52 Optical Interface function for
         10GBASE-R PCS-49";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity LR4-PMD-40G {
      base "optical-interface-func";
      description
        "LR4-PMD-clause-87 Optical Interface function for
         40GBASE-R PCS-82";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity ER4-PMD-40G {
      base "optical-interface-func";
      description
        "ER4-PMD-clause-87 Optical Interface function for
         40GBASE-R PCS-82";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity FR-PMD-40G {
      base "optical-interface-func";
      description
        "FR-PMD-clause-89 Optical Interface function for
         40GBASE-R PCS-82";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity LR4-PMD-100G {
      base "optical-interface-func";
      description
        "LR4-PMD-clause-88 Optical Interface function for
         100GBASE-R PCS-82";
      reference "MEF63: Subscriber Layer 1 Service Attributes";
    }

    identity ER4-PMD-100G {
      base "optical-interface-func";
      description
        "ER4-PMD-clause-88 Optical Interface function for
```

```
           100GBASE-R PCS-82";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity service-performance-metric {
         description
           "Base identity of service-specific performance metric";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity one-way-delay {
         base "service-performance-metric";
         description "one way delay.";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity one-way-errored-second {
         base "service-performance-metric";
         description "one way errored second";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity one-way-severely-errored-second {
         base "service-performance-metric";
         description "one way severely errored second";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity one-way-unavailable-second {
         base "service-performance-metric";
         description "one way unavailable second";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       identity one-way-availability {
         base "service-performance-metric";
         description "one way availability";
         reference "MEF63: Subscriber Layer 1 Service Attributes";
       }

       grouping otn-link-bandwidth {
         description "link bandwidth attributes for OTN";
         list odulist {
           key "odu-type";
           description
             "OTN bandwidth definition";
           leaf odu-type {
             type identityref {
```

```
              base odu-type;
            }
            description "ODU type";
          }
          leaf number {
            type uint16;
            description "Number of ODUs";
          }
        }
      }

      grouping otn-path-bandwidth {
        description
          "path bandwidth attributes for OTN";
        leaf odu-type {
          type identityref {
            base odu-type;
          }
          description "ODU type";
        }
        choice oduflex-type {
          when "odu-type = 'ODUflex' or 'ODUflex-resizable'" {
            description
              "applicable when odu-type is ODUflex or ODUflex-resizable";
          }
          description
            "Types of ODUflex used to compute the ODUflex
             nominal bit rate.";
          reference
            "Table 7-2 of G.709";
          case generic {
            leaf nominal-bit-rate {
              type uint64;
              units "bps";
              mandatory true;
              description
                "Nominal ODUflex bit rate.";
            }
          }
          case cbr {
            leaf client-type {
              type identityref {
                base client-signal;
              }
              mandatory true;
              description
                "The CBR client signal for an ODUflex(CBR).";
            }
```

```
         }
         case gfp-n-k {
           leaf gfp-n {
             type uint8 {
               range "1..80";
             }
             mandatory true;
             description
               "The value of n for an ODUflex(GFP,n,k).";
             reference
               "Tables 7-8 and L-7 of G.709";
           }
           leaf gfp-k {
             type gfp-k;
             description
               "The value of k for an ODUflex(GFP,n,k).
                If omitted, it is calculated from the value of gfp-n
                as described in Table 7-8 of G.709";
             reference
               "Tables 7-8 and L-7 of G.709";
           }
         }
         case flexe-client {
           leaf flexe-client {
             type flexe-client-rate;
             mandatory true;
             description
               "The rate of the FlexE-client for an ODUflex(IMP,s).";
           }
         }
         case flexe-aware {
           leaf flexe-aware-n {
             type uint16;
             mandatory true;
             description
               "The rate of FlexE-aware client signal
                for ODUflex(FlexE-aware)";
           }
         }
         case packet {
           leaf opuflex-payload-rate {
             type uint64;
             units "Kbps";
             mandatory true;
             description
               "Either the GFP-F encapsulated packet client nominal
                bit rate for an ODUflex(GFP) or the 64b/66b encoded
                packet client nominal bit rate for an ODUflex(IMP).";
```

```
          }
        }
      }
    }

    grouping otn-label-range-info {
      description
        "label range information for OTN, dependent on the
         range-type, must be used together with the following
         groupings: otn-label-start-end and otn-label-step. ";
      leaf range-type {
        type otn-label-range-type;
        description "The type of range (e.g., TPN or TS)
           to which the label range applies";
      }
      leaf tsg {
        type identityref {
          base tributary-slot-granularity;
        }
        description
          "Tributary slot granularity (TSG) to which the label range
           applies.
           This leaf must be present when the range-type is TS;
           This leaf may be omitted when mapping an ODUk over an OTUk
           Link. In this case the range-type is tpn, with only one
           entry (ODUk), and the tpn range has only one value (1).";
        reference
          "G.709/Y.1331, February 2016: Interfaces for the
           Optical Transport Network (OTN)";
      }
      leaf-list odu-type-list {
        type identityref {
          base odu-type;
        }
        description
          "List of ODU types to which the label range applies.
           An Empty odu-type-list means that the label range
           applies to all the supported ODU types.";
      }
      leaf priority {
        type uint8;
        description
          "Priority in Interface Switching Capability
           Descriptor (ISCD).";
        reference "RFC4203.";
      }
    }
```

```
     grouping otn-label-start-end {
       description
         "The OTN label-start or label-end used to specify an OTN label
          range. this grouping is dependent on the range-type,
          must be used together with the following groupings:
          otn-label-range-info and otn-label-step.";
       choice range-type {
         description
           "OTN label range type, either TPN range or TS range";
         case trib-port {
           leaf otn-tpn {
             when "../../../range-type = 'trib-port'" {
               description
                 "valid only when range-type represented by trib-port";
             }
             type otn-tpn;
             description
               "Tributary Port Number.";
             reference
               "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
           }
         }
         case trib-slot {
           leaf otn-ts {
             when "../../../range-type = 'trib-slot'" {
               description
                 "valid only when range-type represented by trib-slot";
             }
             type otn-ts;
             description
               "Tributary Slot Number.";
             reference
               "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
           }
         }
       }
     }

     grouping otn-label-hop {
       description "OTN Label. ";
       reference "RFC7139, section 6. ";
       leaf otn-tpn {
         type otn-tpn;
         description
           "Tributary Port Number.";
         reference
```

```
           "RFC7139: GMPLS Signaling Extensions for Control of Evolving
            G.709 Optical Transport Networks.";
       }
       leaf tsg {
         type identityref {
           base tributary-slot-granularity;
         }
         description "Tributary slot granularity.";
         reference
           "G.709/Y.1331, February 2016: Interfaces for the
            Optical Transport Network (OTN)";
       }
       leaf ts-list {
         type string {
             pattern "([1-9][0-9]{0,3}(-[1-9][0-9]{0,3})?"
                   + "(,[1-9][0-9]{0,3}(-[1-9][0-9]{0,3})?)*)";
           }
           description
             "A list of available tributary slots ranging
              from 1 to 4095. If multiple values or
              ranges are given, they all must be disjoint
              and must be in ascending order.
              For example 1-20,25,50-1000.";
           reference
             "RFC 7139: GMPLS Signaling Extensions for Control
              of Evolving G.709 Optical Transport Networks";
       }
     }

     grouping otn-label-step {
       description
         "Label step for OTN, dependent on the range-type,
          must be used together with the following groupings:
          otn-label-range-info and otn-label-start-end. ";
       choice range-type {
         description
           "OTN label range type, either TPN range or TS range";
         case trib-port {
           leaf otn-tpn {
             when "../../../range-type = 'trib-port'" {
               description
                 "valid only when range-type represented by trib-port";
             }
             type otn-tpn;
             description
               "Label step which represents possible increments for
                Tributary Port Number.";
             reference
```

```
               "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
           }
         }
         case trib-slot {
           leaf otn-ts {
             when "../../../range-type = 'trib-slot'" {
               description
                 "valid only when range-type represented by trib-slot";
             }
             type otn-ts;
             description
               "Label step which represents possible increments for
                Tributary Slot Number.";
             reference
               "RFC7139: GMPLS Signaling Extensions for Control of
                Evolving G.709 Optical Transport Networks.";
           }
         }
       }
     }
   }
   <CODE ENDS>
```

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.

The YANG module in this document defines layer 1 type definitions (i.e., typedef, identity and grouping statements) in YANG data modeling language to be imported and used by other layer 1 technology-specific modules. When imported and used, the resultant schema will have data nodes that can be writable, or readable. The access to such 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.

The security considerations spelled out in the YANG 1.1 specification [RFC7950] apply for this document as well.

7. IANA Considerations

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

```
URI: urn:ietf:params:xml:ns:yang:ietf-layer1-types
Registrant Contact: The IESG
XML: N/A; the requested URI is an XML namespace.
```

This document registers following YANG modules in the YANG Module Names registry [RFC7950].

```
name:         ietf-layer1-types
namespace:    urn:ietf:params:xml:ns:yang:ietf-layer1-types
prefix:       l1-types
reference:    RFC XXXX
```

8. Acknowledgements

The authors and the working group give their sincere thanks for Robert Wilton for the YANG doctor review, and Tom Petch for his comments during the model and document development.

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Appendix A. Examples of OTN Label Ranges

This appendix provides some examples of how the TPN and TS label ranges described in Table 3 and Table 4 of [RFC7139] can be represented in YANG using the groupings defined in this document.

It also considers the OTUk links in addition to HO-ODUk links.

The JSON code examples provided in this appendix provides some embedded comments following the conventions in section 3.2 of [I-D.ietf-ccamp-transport-nbi-app-statement] and have been folded using the tool in [RFC8792].

```
========== NOTE: '\\' line wrapping per BCP XXX (RFC XXXX) ==========

{
  "examples of label-restrictions for different OTN Links": [
    {
      "// ": "HO-ODU1 or OTU1 Link",
      "label-restrictions": {
        "label-restriction": [
          {
            "index ": 1,
            "// ___DEFAULT___ restriction": "inclusive",
```

```
               "range-type": "label-range-trib-port",
               "// ___NOT-PRESENT___ tsg": "",
               "odu-type-list": "[ ODU1 ]",
               "// ___DEFAULT___ priority": 7,
               "// tpn-range": 1,
               "// ___ COMMENT ___": "Since no TS range and no TSG are \
   \reported for ODU1, the link is an OTU1 Link. TS allocation is not n\
   \eeded and TPN shall be set to '1' for mapping ODU1 over OTU1. This \
   \entry is not present if the OTN Link is an HO-ODU1 Link."
             },
             {
               "index ": 2,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-slot",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODU0 ]",
               "// ts-range": "1-2",
               "// ___ COMMENT ___": "Since no TPN range is reportd for\
   \ ODU0 with 1.25G TSG, the TPN allocation rule is fixed (TPN = TS#) \
   \for mapping LO-ODU0 over HO-ODU1 with 1.25G TSG. See Table 4 of [RF\
   \C7139]."
             }
           ]
         }
       },
       {
         "// ": "HO-ODU2 or OTU2 Link",
         "label-restrictions": {
           "label-restriction": [
             {
               "index ": 1,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "// ___NOT-PRESENT___ tsg": "",
               "odu-type-list": "[ ODU2 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": 1,
               "// ___ COMMENT ___": "Since no TS range and no TSG are \
   \reported for ODU2, the link is an OTU2 Link. TS allocation is not n\
   \eeded and TPN shall be set to '1' for mapping ODU2 over OTU2. This \
   \entry is not present if the OTN Link is an HO-ODU2 Link."
             },
             {
               "index ": 2,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-slot",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
```

```
   \ ]",
              "// ___ DEFAULT ___ priority": 7,
              "// ts-range": "1-8"
            },
            {
              "index ": 3,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-port",
              "tsg": "tsg-1.25G ",
              "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// tpn-range": "1-8",
              "// ___ COMMENT ___": "Since this TPN range is reported \
   \for ODUflex and ODU0 with 1.25G TSG, the TPN assignment rule is fle\
   \xible within a common range for mapping LO-ODUflex and LO-ODU0 over\
   \ HO-ODU2 with 1.25G TSG. See Table 4 of [RFC7139]."
            },
            {
              "index ": 4,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-port",
              "tsg": "tsg-1.25G",
              "odu-type-list": "[ ODU1 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// tpn-range": "1-4",
              "// ___ COMMENT ___": "Since this TPN range is reported \
   \for ODU1 with 1.25G TSG, the TPN assignment rule is flexible within\
   \ a common range for mapping LO-ODU1 over HO-ODU2 with 1.25G TSG. Se\
   \e Table 4 of [RFC7139]."
            },
            {
              "index ": 5,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-slot",
              "tsg": "tsg-2.5G",
              "odu-type-list": "[ ODU1 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// ts-range": "1-4",
              "// ___ COMMENT ___": "Since no TPN range is reported fo\
   \r ODU1 with 2.5G TSG, the TPN allocation rule is fixed (TPN = TS#) \
   \for mapping LO-ODU1 over HO-ODU2 with 2.5G TSG. See Table 3 of [RFC\
   \7139]."
            }
          ]
        }
      },
      {
        "// ": "HO-ODU3 or OTU3 Link",
```

```
         "label-restrictions": {
           "label-restriction": [
             {
               "index ": 1,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "// ___NOT-PRESENT___ tsg": "",
               "odu-type-list": "[ ODU3 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": 1,
               "// ___ COMMENT ___": "Since no TS range and no TSG are \
   \reported for ODU3, the link is an OTU3 Link. TS allocation is not n\
   \eeded and TPN shall be set to '1' for mapping ODU3 over OTU3. This \
   \entry is not present if the OTN Link is an HO-ODU3 Link."
             },
             {
               "index ": 2,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-slot",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
   \, ODU2, ODU2e ]",
               "// ___ DEFAULT ___ priority": 7,
               "// ts-range": "1-32"
             },
             {
               "index ": 3,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU2\
   \e ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": "1-32",
               "// ___ COMMENT ___": "Since this TPN range is reported \
   \for ODUflex, ODU0 and ODU2e with 1.25G TSG, the TPN assignment rule\
   \ is flexible within a common range for mapping LO-ODUflex, LO-ODU0 \
   \and LO-ODU2e over HO-ODU3 with 1.25G TSG. See Table 4 of [RFC7139]."
             },
             {
               "index ": 4,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODU1 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": "1-16",
               "// ___ COMMENT ___": "Since this TPN range is reported \
```

```
   \for ODU1 with 1.25G TSG, the TPN assignment rule is flexible within\
   \ a common range for mapping LO-ODU1 over HO-ODU3 with 1.25G TSG. Se\
   \e Table 4 of [RFC7139]."
             },
             {
               "index ": 5,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "tsg": "tsg-1.25G",
               "odu-type-list": "[ ODU2 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": "1-4",
               "// ___ COMMENT ___": "Since this TPN range is reported \
   \for ODU2 with 1.25G TSG, the TPN assignment rule is flexible within\
   \ a common range for mapping LO-ODU2 over HO-ODU3 with 1.25G TSG. Se\
   \e Table 4 of [RFC7139]."
             },
             {
               "index ": 6,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-slot",
               "tsg": "tsg-2.5G",
               "odu-type-list": "[ ODU1, ODU2 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// ts-range": "1-16"
             },
             {
               "index ": 7,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "tsg": "tsg-2.5G ",
               "odu-type-list": "[ ODU2 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": "1-4",
               "// ___ COMMENT ___": "Since this TPN range is reported \
   \for ODU2 with 2.5G TSG, the TPN assignment rule is flexible within \
   \a common range for mapping LO-ODU2 over HO-ODU3. Since no TPN range\
   \ is reported for ODU1 with 2.5G TSG, the TPN allocation rule is fix\
   \ed (TPN = TS#) for mapping LO-ODU1 over HO-ODU3 with 2.5G TSG. See \
   \Table 3 of [RFC7139]."
             }
           ]
         }
       },
       {
         "// ": "HO-ODU4 or OTU4 Link",
         "label-restrictions": {
           "label-restriction": [
```

```
            {
              "index ": 1,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-port",
              "// ___NOT-PRESENT___ tsg": "",
              "odu-type-list": "[ ODU4 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// tpn-range": 1,
              "// ___ COMMENT ___": "Since no TS range and no TSG are \
   \reported for ODU4, the link is an OTU4 Link. TS allocation is not n\
   \eeded and TPN shall be set to '1' for mapping ODU4 over OTU4. This \
   \entry is not present if the OTN Link is an HO-ODU4 Link."
            },
            {
              "index ": 2,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-slot",
              "tsg": "tsg-1.25G",
              "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
   \, ODU2, ODU2e, ODU3 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// ts-range": "1-80"
            },
            {
              "index ": 3,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-port",
              "tsg": "tsg-1.25G",
              "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
   \, ODU2, ODU2e, ODU3 ]",
              "// ___ DEFAULT ___ priority": 7,
              "// tpn-range": "1-80",
              "// ___ COMMENT ___": "Since this TPN range is reported \
   \for any LO-ODUj with 1.25G TSG, the TPN assignment rule is flexible\
   \ within a common range for mapping any LO-ODUj over HO-ODU4 with 1.\
   \25G TSG. See Table 4 of [RFC7139]."
            }
          ]
        }
      },
      {
        "// ": "ODUC1 Link",
        "label-restrictions": {
          "label-restriction": [
            {
              "index ": 1,
              "// ___DEFAULT___ restriction": "inclusive",
              "range-type": "label-range-trib-slot",
```

```
               "tsg": "tsg-5G",
               "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
   \, ODU2, ODU2e, ODU3, ODU4 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// ts-range": "1-20",
               "// ___ COMMENT ___": "Since the TS range is specified f\
   \or any ODUk, the OTN Link is an ODUCn Link."
             },
             {
               "index ": 2,
               "// ___DEFAULT___ restriction": "inclusive",
               "range-type": "label-range-trib-port",
               "tsg": "tsg-5G",
               "odu-type-list": "[ ODUFlex-cbr, ODUFlex-gfp, ODU0, ODU1\
   \, ODU2, ODU2e, ODU3, ODU4 ]",
               "// ___ DEFAULT ___ priority": 7,
               "// tpn-range": "1-10",
               "// ___ COMMENT ___": "Since this TPN range is reported \
   \for any ODUk with 5G TSG, the TPN assignment rule is flexible withi\
   \n a common range for mapping any ODUk over ODUCn with 5G TSG."
             }
           ]
         }
       }
     ]
   }
```


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CCAMP Working Group
Internet-Draft
Intended status: Standards Track
Expires: March 12, 2021

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A Yang Data Model for Optical Impairment-aware Topology
draft-ietf-ccamp-optical-impairment-topology-yang-04

Abstract

In order to provision an optical connection through optical networks, a combination of path continuity, resource availability, and impairment constraints must be met to determine viable and optimal paths through the network. The determination of appropriate paths is known as Impairment-Aware Routing and Wavelength Assignment (IA-RWA) for WSON, while it is known as Impairment-Aware Routing and Spectrum Assigment (IA-RSA) for SSON.

This document provides a YANG data model for the impairment-aware TE topology in optical networks.

Status of This Memo

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Table of Contents

1. Introduction

In order to provision an optical connection (an optical path) through a wavelength switched optical networks (WSONs) or spectrum switched optical networks (SSONs), a combination of path continuity, resource availability, and impairment constraints must be met to determine viable and optimal paths through the network. The determination of appropriate paths is known as Impairment-Aware Routing and Wavelength Assignment (IA-RWA) [RFC6566] for WSON, while it is known as IA-Routing and Spectrum Assigment (IA-RSA) for SSON.

This document provides a YANG data model for the impairment-aware Traffic Engineering (TE) topology in WSONs and SSONs. The YANG model described in this document is a WSON/SSON 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].

The intent of this document is to provide a Yang data model, which can be utilized by a Multi-Domain Service Coordinator (MDSC) to collect states of WSON impairment data from the Transport PNCs to enable impairment-aware optical path computation according to the ACTN Architecture [RFC8453]. The communication between controllers is done via a NETCONF [RFC8341] or a RESTCONF [RFC8040]. Similarly,this model can also be exported by the MDSC to a Customer Network Controller (CNC), which can run an offline planning process to map latter the services in the network.

This document augments the generic TE topology draft [I-D.ietf-teas-yang-te-topo] where possible.

This document defines one YANG module: ietf-optical-impairment-topology (Section 3) according to the new Network Management Datastore Architecture [RFC8342].

1.1. Terminology

Refer to [RFC6566], [RFC7698], and [G.807] 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 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
optical-imp-topo	ietf-optical-impairment-topology	[RFCXXXX]
layer0-types	ietf-layer0-types	[I-D.ietf-ccamp-layer0-types]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[I-D.ietf-teas-yang-te-topo]

Table 1: Prefixes and corresponding YANG modules

[Editor's note: The RFC Editor will replace XXXX with the number assigned to the RFC once this draft becomes an RFC.]

2. Reference Architecture

2.1. Control Plane Architecture

Figure 1 shows the control plane architecture.

```
                             +--------+
                             |  MDSC  |
                             +--------+
    Scope of this ID  ------->   ||
                  |              ||
                  |  +------------------------+
                  |  |        OPTICAL         |
     +---------+  |  |         DOMAIN         |     +---------+
     | Device  |  |  |       CONTROLLER       |     | Device  |
     | config. |  |  +------------------------+     | config. |
     +---------+  v  //          ||          \\     +---------+
    ______|______   //           ||           \\   ______|______
   /      OT     \ //            ||            \\ /      OT     \
   | +--------+  |//           __--__           \\|  +--------+ |
   | |Vend. A |--|----+       (      )       +----|--| Vend. A| |
   | +--------+  |    |   ~-(        )-~    |    |  +--------+ |
   | +--------+  |    +---/              \---+    |  +--------+ |
   | |Vend. B |--|--+    /                \    +--|--| Vend. B| |
   | +--------+  |  +---(   OLS Segment    )---+  |  +--------+ |
   | +--------+  |  +---(                  )---+  |  +--------+ |
   | |Vend. C |--|--+    \                /    +--|--| Vend. C| |
   | +--------+  |    +---\              /---+    |  +--------+ |
   | +--------+  |    |   ~-(        )-~    |    |  +--------+ |
   | |Vend. D |--|----+       (__  __)       +----|--| Vend. D| |
   | +--------+  |               --               |  +--------+ |
   \_____________/                                \_____________/
             ^                                        ^
             |                                        |
             |                                        |
            Scope of [I-D.ietf-ccamp-dwdm-if-param-yang]
```

Figure 1: Scope of draft-ietf-ccamp-dwdm-if-param-yang

The models developed in this document is an abstracted Yang model that may be used in the interfaces between the MDSC and the Optical Domain Controller (aka MPI) and between the Optical Domain Controller and the Optical Device (aka SBI) in Figure 1. It is not intended to support a detailed low-level DWDM interface model. DWDM interface model is supported by the models presented in [I-D.ietf-ccamp-dwdm-if-param-yang].

2.2. Transport Data Plane

This section provides the description of the reference optical network architecture and its relevant components to support optical impairment-aware path computation.

Figure 2 shows the reference architecture.

```
     +-------------------+                      +-------------------+
     |     ROADM Node    |                      |     ROADM Node    |
     |                   |                      |                   |
     | PA +--------+ BA  |         ILA          | PA +--------+ BA  |
     | +-+|  WSS/  |+-+  |  _____  +--+  _____  | +-+|  WSS/  |+-+  |
   --|-| ||Filter  |-| |-|-()____)-|  |-()____)-|-| ||Filter  |-| |-|--
     | +-+|        |+-+  |         +--+         | +-+|        |+-+  |
     |    +--------+     | optical              |    +--------+     |
     |       | | |       |  fiber               |       | | |       |
     |       o o o       |                      |       o o o       |
     |   transponders    |                      |   transponders    |
     +-------------------+                      +-------------------+
                        OTS Link       OTS Link
                       <---------->   <---------->
                                OMS Link
                    <-------------------------------->
```

PA: Pre-Amplifieror
BA: Booster Amplifier
ILA: In-Line Amplifier

Figure 2: Reference Architecture for Optical Transport Network

BA (on the left side ROADM) is the ingress Amplifier and PA (on the right side ROADM is the egress amplifier for the OMS link shown in Figure 2.

2.3. OMS Media Links

According to [G.872], OMS Media Link represents a media link between two ROADMs. Specifically, it originates at the ROADM's Filter in the source ROADM and terminates at the ROADM's Filter in the destination ROADM.

OTS Media Link represents a media link:

(i) between ROADM's BA and ILA;
(ii) between a pair of ILAs;
(iii) between ILA and ROADM's PA.

OMS Media link can be decomposed in a sequence of OTS links type (i), (ii), and (iii) as discussed above. OMS Media link would give an abstracted view of impairment data (e.g., power, OSNR, etc.) to the network controller.

For the sake of optical impairment evaluation OMS Media link can be also decomposed in a sequence of elements such as BA, fiber section, ILA, concentrated loss and PA.

[Editor’s note: text below related to [G.807] needs to be revised! [G.807] is now in publication process.]

2.3.1. Optical Tributary Signal (OTSi)

The OTSi is defined in ITU-T Recommendation G.959.1, section 3.2.4 [G.959.1]. The YANG model defined below assumes that a single OTSi consists of a single modulated optical carrier. This single modulated optical carrier conveys digital information. Characteristics of the OTSi signal are modulation scheme (e.g. QPSK, 8-QAM, 16-QAM, etc.), baud rate (measure of the symbol rate), pulse shaping (e.g. raised cosine - complying with the Nyquist inter symbol interference criterion), etc.

2.3.2. Optical Tributary Signal Group (OTSiG)

The definition of the OTSiG is currently being moved from ITU-T Recommendation G.709 [G.709] to the new draft Recommendation G.807 (still work in progress) [G.807]. The OTSiG is an electrical signal that is carried by one or more OTSi’s. The relationship between the OTSiG and the the OTSi’s is described in ITU-T draft Recommendation G.807, section 10.2 [G.807]. The YANG model below supports both cases: the single OTSi case where the OTSiG contains a single OTSi (see ITU-T draft Recommendation G.807, Figure 10-2) and the multiple OTSi case where the OTSiG consists of more than one OTSi (see ITU-T draft Recommendation G.807, Figure 10-3). From a layer 0 topology YANG model perspective, the OTSiG is a logical construct that associates the OTSi’s, which belong to the same OTSiG. The typical application of an OTSiG consisting of more than one OTSi is inverse multiplexing. Constraints exist for the OTSi’s belonging to the same OTSiG such as: (i) all OTSi’s must be co-routed over the same optical fibers and nodes and (ii) the differential delay between the different OTSi’s may not exceed a certain limit. Example: a 400Gbps client signal may be carried by 4 OTSi’s where each OTSi carries 100Gbps of client traffic.

```
                                  OTSiG
           _________________________/\___________________________
          /                                                      \
                                    m=7
   - - - +---------------------------X---------------------------+ - - -
   / / / |                                                       | / / /
    / / /|      OTSi         OTSi         OTSi         OTSi      |/ / /
   / / / |        ^            ^            ^            ^       | / / /
    / / /|        |            |            |            |       |/ / /
   / / / |        |            |            |            |       | / / /
    / / /|        |            |            |            |       |/ / /
    -4  -3  -2  -1   0   1   2   3   4   5   6   7   8   9  10  11  12
   --+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---
                                   n = 4
                  K1           K2           K3           K4
```

Figure 3: MC Example containing all 4 OTSi signals of an OTSiG

2.3.3. Media Channel (MC)

The definition of the MC is currently being moved from ITU-T Recommendation G.872 [G.872] to the new draft Recommendation G.807 (still work in progress) [G.807]. Section 3.2.2 defines the term MC and section 7.1.2 provides a more detailed description with some examples. The definition of the MC is very generic (see ITU-T draft Recommendation G.807, Figure 7-1). In the YANG model below, the MC is used with the following semantics:

The MC is an end-to-end topological network construct and can be considered as an "optical pipe" with a well-defined frequency slot between one or more optical transmitters each generating an OTSi and the corresponding optical receivers terminating the OTSi's. If the MC carries more than one OTSi, it is assumed that these OTSi's belong to the same OTSiG.

```
                                    m=8
     +-------------------------------X-------------------------------+
     |                               |                               |
     |     +----------X----------+   |   +----------X----------+     |
     |     |        OTSi         |       |        OTSi         |     |
     |     |          ^          |   |   |          ^          |     |
     |     |          |          |       |          |          |     |
    -4  -3  -2  -1   0   1   2   3   4   5   6   7   8   9  10  11  12
   --+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+-
                      |             n=4             |
                      K1                            K2

     <------------------------ Media Channel ----------------------->
```

Figure 4: Figure Caption TBA

The frequency slot of the MC is defined by the n value defining the central frequency of the MC and the m value that defines the width of the MC following the flexible grid definition in ITU-T Recommendation G.694.1 [G.694.1]. In this model, the effective frequency slot as defined in ITU-T draft Recommendation G.807 is equal to the frequency slot of this end-to-end MC. It is also assumed that ROADM devices can switch MCs. For various reasons (e.g. differential delay), it is preferred to use a single MC for all OTSi's of the same OTSiG. It may however not always be possible to find a single MC for carrying all OTSi's of an OTSiG due to spectrum occupation along the OTSiG path.

2.3.4. Media Channel Group (MCG)

The definition of the MCG is currently work in progress in ITU-T and is defined in section 7.1.3 of the new ITU-T draft Recommendation G.807 (still work in progress) [G.807]. The YANG model below assumes that the MCG is a logical grouping of one or more MCs that are used to to carry all OTSi's belonging to the same OTSiG.

The MCG can be considered as an association of MCs without defining a hierarchy where each MC is defined by its (n,m) value pair. An MCG consists of more than one MC when no single MC can be found from source to destination that is wide enough to accommodate all OTSi's (modulated carriers) that belong to the same OTSiG. In such a case the set of OTSi's belonging to a single OTSiG have to be split across 2 or more MCs.

```
                                   MCG1 = {M1.1, M1.2}
          __________________________/\________________________
         /                                                    \
                     M1.1                  M2          M1.2
          ____________/\____________  _____/\_____  ____/\____
         /                          \/            \/          \
   - - - +---------------------------+-------------+-----------+ - - -
   / / / |                           | / / / / / / |           | / / /
    / / /|    OTSi    OTSi    OTSi   |/ / / / / / /|    OTSi   |/ / /
   / / / |     ^       ^       ^     | / / / / / / |     ^     | / / /
    / / /|     |       |       |     |/ / / / / / /|     |     |/ / /
   / / / |     |       |       |     | / / / / / / |     |     | / / /
    / / /|     |       |       |     |/ / / / / / /|     |     |/ / /
        -7    -4    -1 0 1 2 3 4 5 6 7 8    ...    14    17    20
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                       n=0                               n=17
               K1      K2      K3                        K4
```

Figure 5: Figure Caption TBA

The MCG is relevant for path computation because all end-to-end MCs belonging to the same MCG have to be co-routed, i.e., have to follow the same path. Additional constraints may exist (e.g. differential delay).

2.4. Amplifiers

Optical amplifiers are in charge of amplifying the optical signal in the optical itself without any electrical conversion. There are three main technologies to build amplifiers: Erbium Doped Fiber Amplifier (EDFA), Raman Fiber Amplifier (RFA), and Semiconductor Optical Amplifier (SOA). Nowadays, most of optical networks uses EDFAs. However, RFA has an attractive feature that it works in any wavelength band with a similar or lower noise figures compared to EDFA. On the other hand, RFAs consumes more power and are more expensive than EDFAs.

Amplifiers can be classified according to their location in the communication link. There are three basic types of amplifiers: ILA, Pre-Amplifier and Booster. ILA is In-Line Amplifier which is a separate node type while Pre-Amplifier and Booster Amplifier are integral elements of ROADM node. From a data modeling perspective, Pre-Amplifier and Booster Amplifier are internal functions of a ROADM node and as such these elements are hidden within ROADM node. In this document, we would avoid internal node details, but attempt to abstract as much as possible.

One modeling consideration of the ROADM internal is to model power parameter through the ROADM, factoring the output power from the Pre-Amplifier minus the ROADM power loss would give the input power to the Booster Amplifier. In other words, Power_in (@ ROADM Booster) = Power_out (@ ROADM Pre-Amplifier) - Power_loss (@ ROADM WSS/Filter).

2.5. Transponders

A Transponder is the element that sends and receives the optical signal from a fiber. A transponder is typically characterized by its data rate and the maximum distance the signal can travel. Channel frequency, per channel input power, FEC and Modulation are also associated with a transponder. From a path computation point of view, the selection of the compatible source and destination transponders is an important factor for optical signal to traverse through the fiber. There are three main approaches to determine optical signal compatibility. Application Code based on G.698.2 is one approach that only checks the code at both ends of the link. Another approach is organization codes that are specific to an organization or a vendor. The third approach is specify all the relevant parameters explicitly, e.g., FEC type, Modulation type, etc.

[Editor's note: The current YANG model described in Section 3 with respect to the relationship between the transponder attributes and the OTSi will need to be investigated in the future revision]

2.6. WSS/Filter

WSS separates the incoming light input spectrally as well as spatially, then chooses the wavelength that is of interest by deflecting it from the original optical path and then couple it to another optical fibre port. WSS/Filter is internal to ROADM. So this document does not model the inside of ROADM.

2.7. Optical Fiber

There are various optical fiber types defined by ITU-T. There are several fiber-level parameters that need to be factored in, such as, fiber-type, length, loss coefficient, pmd, connectors (in/out).

ITU-T G.652 defines Standard Singlemode Fiber; G.654 Cutoff Shifted Fiber; G.655 Non-Zero Dispersion Shifted Fiber; G.656 Non-Zero Dispersion for Wideband Optical Transport; G.657 Bend-Insensitive Fiber. There may be other fiber-types that need to be considered.

2.8. ROADM Node Architectures

The ROADM node architectures in today's dense wavelength division multiplexing (DWDM) networks can be categorized as follows:

- o Integrated ROADM architecture with integrated optical transponders
- o Integrated ROADM architecture with integrated optical transponders and single channel add/drop ports for remote optical transponders
- o Disaggregated ROADM architecture where the ROADM is subdivided into degree, add/drop, and optical transponder subsystems handled as separate network elements

The TE topology YANG model augmentations including optical impairments for DWDM networks defined below intend to cover all the 3 categories of ROADM architectures listed above. In the case of a disaggregated ROADM architecture, it is assumed that optical domain controller already performs some form of abstraction and presents the TE-node representing the disaggregated ROADM in the same way as an integrated ROADM with integrated optical transponders if the optical transponder subsystems and the add/drop subsystems are collocated (short fiber links not imposing significant optical impairments).

The different ROADM architectures are briefly described and illustrated in the following subsections.

[Editor's note: The modeling of remote optical transponders located for example in the client device with a single channel link between the OT and the add/drop port of the ROADM requires further investigations and will be addressed in a future revision of this document.]

2.8.1. Integrated ROADM Architecture with Integrated Optical Transponders

Figure 2 and Figure 6 below show the typical architecture of an integrated ROADM node, which contains the optical transponders as an integral part of the ROADM node. Such an integrated ROADM node provides DWDM interfaces as external interfaces for interconnecting the device with its neighboring ROADMs (see OTS link above). The number of these interfaces denote also the degree of the ROADM. A degree 3 ROADM for example has 3 DWDM links that interconnect the ROADM node with 3 neighboring ROADMs. Additionally, the ROADM provides client interfaces for interconnecting the ROADM with client devices such as IP routers or Ethernet switches. These client interfaces are the client interfaces of the integrated optical transponders.

```
               . . . . . . . . . . . . . . . . . .
         +-----.-------------------------------- .-----+
         |     .              ROADM              .     |
         |     .   /|   +-----------------+   |\   .     |
    Line |     .  / |--|                 |--| \  .     | Line
    WEST |  /| . |  |--|                 |--|  | . |\  | EAST
   ------+-/ |-.-|  |--|       OCX       |--|  |-.-| \-+-----
   ------+-\ |-.-|  |--|                 |--|  |-.-| /-+-----
         |  \| . |  |--|                 |--|  | . |/  |
         |     .  \ |--|                 |--| /  .     |
         |     .   \|   +-----------------+   |/   .     |
         |     .                                 .     |
         |     .     +---+ +---+ +---+ +---+     .     |
         |     .     | O | | O | | O | | O |     .     |
         |     .     | T | | T | | T | | T |     .     |
         |     .     +---+ +---+ +---+ +---+     .     |
         |     .      | |   | |   | |   | |      .     |
         +-----.------+-+---+-+---+-+---+-+------.-----+
               . . . .|.| . |.| . |.| . |.|. . . .
                      | |   | |   | |   | |     TE Node
                        Client Interfaces
```

Figure 6: ROADM Architectiure with Integrated Transponders

2.8.2. Integrated ROADMs with Integrated Optical Transponders and Single Channel Add/Drop Interfaces for Remote Optical Transponders

Figure 7 below shows the extreme case where all optical transponders are not integral parts of the ROADM but are separate devices that are interconnected with add/drop ports of the ROADM. If the optical transponders and the ROADM are collocated and if short single channel fiber links are used to interconnect the optical transponders with an add/drop port of the ROADM, the optical domain controller may present these optical transponders in the same way as integrated optical transponders. If, however, the optical impairments of the single channel fiber link between the optical transponder and the add/drop port of the ROADM cannot be neglected, it is necessary to represent the fiber link with its optical impairments in the topology model This also implies that the optical transponders belong to a separate TE node

[Editor's note: this requires further study].

```
               . . . . . . . . . . . . . . . . . .
               .       Abstracted ROADM          .
         +-----.-------------------------------- .-----+
         |     .              ROADM              .     |
         |     .   /|  +-----------------+  |\   .     |
    Line |     .  / |--|                 |--| \  .     | Line
    WEST |  /| . |  |--|                 |--|  | . |\  | EAST
   ------+-/ |-.-|  |--|       OCX       |--|  |-.-| \-+-----
   ------+-\ |-.-|  |--|                 |--|  |-.-| /-+-----
         |  \| . |  |--|                 |--|  | . |/  |
         |     .  \ |--|                 |--| /  .     |
         |     .   \|  +-----------------+  |/   .     |
         +-----.---------|----|---|----|---------.-----|
    Colored OT .       +-+   ++   ++   +-+       .
    line I/F   .       |     |     |     |       .
               .     +---+ +---+ +---+ +---+     .
               .     | O | | O | | O | | O |     .
               .     | T | | T | | T | | T |     .
               .     +---+ +---+ +---+ +---+     .
               . . . .|.| . |.| . |.| . |.|. . . .
                      | |   | |   | |   | |    TE Node
                        Client Interfaces
```

          Figure 7: ROADM Architectiure with Remote Transponders

2.8.3. Disaggregated ROADMs Subdivided into Degree, Add/Drop, and Optical Transponder Subsystems

Recently, some DWDM network operators started demanding ROADM subsystems from their vendors. An example is the OpenROADM project where multiple operators and vendors are developing related YANG models. The subsystems of a disaggregated ROADM are: single degree subsystems, add/drop subsystems and optical transponder subsystems. These subsystems separate network elements and each network element provides a separate management and control interface. The subsystems are typically interconnected using short fiber patch cables and form together a disaggregated ROADM node. This disaggregated ROADM architecture is depicted in Figure 8 below.

As this document defines TE topology YANG model augmentations [I-D.ietf-teas-yang-te-topo] for the TE topology YANG model provided at the north-bound interface of the optical domain controller, it is a valid assumption that the optical domain controller abstracts the subsystems of a disaggregated ROADM and presents the disaggregated ROADM in the same way as an integrated ROADM hiding all the interconnects that are not relevant from an external TE topology view.

```
              . . . . . . . . . . . . . . . . . .
              .        Abstracted ROADM          .
        +-----.----------+            +----------.-----+
        | Degree 1       |            |       Degree 2 |
   Line |     .  +-----+ |            + +-----+  .     | Line
    1   |  /| .  |  W  |-|------------|-|  W  |  .  |\  |  2
   -----+-/ |-.--|  S  ********  ********  S  |--.-| \-+-----
   -----+-\ |-.--|  S  | |    *  *    | |  S  |--.-| /-+-----
        |  \| .  |     |-|-+  *  *  +-|-|     |  .  |/  |
        |     .  +-+-+-+ | |  *  *  | | +-+-+-+  .     |
        +-----.----|-----+ |  *  *  | +-----|----.-----+
              .    |       |  *  *  |       |    .
        +-----.----|-----+ |  *  *  | +-----|----.-----+
        | Degree 4 |     | |  *  *  | |     | Degree 3 |
   Line |     .  +-----+ | |  *  *  | | +-----+  .     | Line
    4   |  /| .  |  W  |-|-|--*--*--+ | |  W  |  .  |\  |  3
   -----+-/ |-.--|  S  | | +--*--*----|-|  S  |--.-| \-+-----
   -----+-\ |-.--|  S  |-|----*--*----|-|  S  |--.-| /-+-----
        |  \| .  |     | |    *  *    | |     |  .  |/  |
        |     .  +--*--+ |    *  *    | +--*--+  .     |
        +-----.-----*----+    *  *    +----*-----.-----+
              .     *         *  *         *     .
              .  +--*---------*--*---------*--+  .
              .  |          ADD               |  .
              .  |          DROP              |  .
              .  +----------------------------+  .
    Colored OT  .     |     |     |     |     .
     Line I/F   .   +---+ +---+ +---+ +---+   .
                .   | O | | O | | O | | O |   .
                .   | T | | T | | T | | T |   .
                .   +---+ +---+ +---+ +---+   .
                . . .|.| . |.| . |.| . |.|. . .
                     | |   | |   | |   | |     TE Node
                       Client Interfaces
```

Figure 8: Disaggregated ROADM Architecture with Remote Transponders

2.8.4. Optical Impairments Imposed by ROADM Nodes

When an optical OTSi signal traverses a ROADM node, optical impairments are imposed on the signal by various passive or active optical components inside the ROADM node. Examples of optical impairments are:

- o Chromatic dispersion (CD)
- o Polarization mode dispersion (PMD)
- o Polarization dependent loss (PDL)

- Optical amplifier noise due to amplified spontaneous emission (ASE)
- In-band cross-talk
- Filtering effects (for further study)

A ROADM node contains a wavelength selective photonic switching function (WSS)that is capable of switching media channels (MCs) described in Section 2.3.4. These MCs can be established between two line ports of the ROADM or between a line port and an Add/Drop port of the ROADM. The Add/Drop ports of a ROADM are those ports to which optical transponders are connected. Typically, this is a single channel signal (single OTSi), but principally this could also be a group of OTSi signals. The optical impairments associated with these MCs are different and the paths of the MCs inside the ROADM node can be categorized as follows:

- Express path: MC path between two line ports of the ROADM (unidirectional)

- Add Path: MC path from an Add port to a line port of the ROADM

- Drop path: MC path from a line port to a Drop port of the ROADM

Due to the symmetrical architecture of the ROADM node, the optical impairments associated with the express path are typically the same between any two line ports of the ROADM whereas the optical impairments for the add and drop paths are different and therefore have to be modeled separately.

The optical impairments associated with each of the three types of ROADM-node-internal paths described above are modeled as optical impairment parameter sets. These parameter sets are modeled as an augmentation of the te-node-attributes defined in [I-D.ietf-teas-yang-te-topo]. The te-node-attributes are augmented with a list of roadm-path-impairments for the three ROADM path types distinguished by the impairment-type. Each roadm-path-impairments list entry contains the set of optical impairment parameters for one of the three path types indicated by the impairment-type. For the optical feasibility calculation based on the optical impairments, it is necessary to know whether the optical power of the OTSi stays within a certain power window. This is reflected by some optical power related parameters such as loss parameters or power parameters, which are included in the optical impairment parameter sets (see tree view in Section 3).

[I-D.ietf-teas-yang-te-topo] defines a connectivity matrix and a local link connectivity list for the TE node. The connectivity matrix describes the connectivity for the express paths between the different lines of the ROADM and the local link connectivity list describes the connectivity for the Add and Drop paths of the ROADM. These matrices are augmented with a new roadm-path-impairment matrix element, an add-path-impairment, and drop-path-impairment matrix element, respectively, which are defined as a pointer to the corresponding entry in the roadm-path-impairments list (leaf-ref).

[Editor's note: this section is still work in progress]

3. YANG Model (Tree Structure)

```
module: ietf-optical-impairment-topology
  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw optical-impairment-topology!
  augment /nw:networks/nw:network/nt:link/tet:te/
  tet:te-link-attributes:
    +--ro OMS-attributes
       +--ro generalized-snr?                         decimal64
       +--ro equalization-mode                        identityref
       +--ro (power-param)?
       |  +--:(channel-power)
       |  |  +--ro nominal-channel-power?             decimal64
       |  +--:(power-spectral-density)
       |     +--ro nominal-power-spectral-density?   decimal64
       +--ro media-channel-group* [i]
       |  +--ro i                 int16
       |  +--ro media-channels* [flexi-n]
       |     +--ro flexi-n      uint16
       |     +--ro flexi-m?     uint16
       |     +--ro OTSiG-ref?   -> /nw:networks/network/node/tet:te/
             tunnel-termination-point/OTSiG-element/OTSiG-identifier
       |     +--ro OTSi-ref?    -> /nw:networks/network/node/tet:te/
             tunnel-termination-point/
             OTSiG-element[OTSiG-identifier=current()/../OTSiG-ref]/
             OTSiG-container/OTSi/OTSi-carrier-id
       +--ro OMS-elements* [elt-index]
          +--ro elt-index    uint16
          +--ro uid?         string
          +--ro type         identityref
          +--ro element
             +--ro (element)?
                +--:(amplifier)
                |  +--ro amplifier
                |     +--ro type-variety    string
                |     +--ro operational
                |        +--ro actual-gain                decimal64
                |        +--ro tilt-target                decimal64
                |        +--ro out-voa                    decimal64
```

```
                   |        +--ro in-voa                        decimal64
                   |        +--ro (power-param)?
                   |           +--:(channel-power)
                   |           |  +--ro nominal-channel-power?
                   |           |                                decimal64
                   |           +--:(power-spectral-density)
                   |              +--ro nominal-power-spectral-density?
                   |                      decimal64
                   +--:(fiber)
                   |  +--ro fiber
                   |     +--ro type-variety    string
                   |     +--ro length          decimal64
                   |     +--ro loss-coef       decimal64
                   |     +--ro total-loss      decimal64
                   |     +--ro pmd?            decimal64
                   |     +--ro conn-in?        decimal64
                   |     +--ro conn-out?       decimal64
                   +--:(concentratedloss)
                      +--ro concentratedloss
                         +--ro loss?   decimal64
    augment /nw:networks/nw:network/nw:node/tet:te/
    tet:tunnel-termination-point:
      +--ro OTSiG-element* [OTSiG-identifier]
      |  +--ro OTSiG-identifier    int16
      |  +--ro OTSiG-container
      |     +--ro OTSi* [OTSi-carrier-id]
      |        +--ro OTSi-carrier-id           int16
      |        +--ro OTSi-carrier-frequency?   decimal64
      |        +--ro OTSi-signal-width?        decimal64
      |        +--ro channel-delta-power?      decimal64
      +--ro transponders-list* [transponder-id]
         +--ro transponder-id                      uint32
         +--ro (mode)?
         |  +--:(G.692.2)
         |  |  +--ro standard-mode?                standard-mode
         |  +--:(organizational-mode)
         |  |  +--ro operational-mode?             operational-mode
         |  |  +--ro organization-identifier?      vendor-identifier
         |  +--:(explicit-mode)
         |     +--ro available-modulation-types*   identityref
         |     +--ro configured-modulation-type?   identityref
         |     +--ro available-baud-rates*         uint32
         |     +--ro configured-baud-rate?         uint32
         |     +--ro available-FEC-types*          identityref
         |     +--ro configured-FEC-type?          identityref
         |     +--ro FEC-code-rate?                decimal64
         |     +--ro FEC-threshold?                decimal64
         +--ro power?                              int32
```

```
          +--ro power-min?                              int32
          +--ro power-max?                              int32
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:tunnel-termination-point:
       +--ro transponder-list* [carrier-id]
          +--ro carrier-id    uint32
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:te-node-attributes:
       +--ro roadm-path-impairments* [roadm-path-impairments-id]
          +--ro roadm-path-impairments-id    uint32
          +--ro (impairment-type)?
             +--:(roadm-express-path)
             |  +--ro roadm-express-path
             |     +--ro roadm-pmd?                decimal64
             |     +--ro roadm-cd?                 decimal64
             |     +--ro roadm-pdl?                decimal64
             |     +--ro roadm-inband-crosstalk?   decimal64
             |     +--ro roadm-maxloss?            decimal64
             +--:(roadm-add-path)
             |  +--ro roadm-add-path
             |     +--ro roadm-pmd?                decimal64
             |     +--ro roadm-cd?                 decimal64
             |     +--ro roadm-pdl?                decimal64
             |     +--ro roadm-inband-crosstalk?   decimal64
             |     +--ro roadm-maxloss?            decimal64
             |     +--ro roadm-pmax?               decimal64
             |     +--ro roadm-osnr?               decimal64
             |     +--ro roadm-noise-figure?       decimal64
             +--:(roadm-drop-path)
                +--ro roadm-drop-path
                   +--ro roadm-pmd?                decimal64
                   +--ro roadm-cd?                 decimal64
                   +--ro roadm-pdl?                decimal64
                   +--ro roadm-inband-crosstalk?   decimal64
                   +--ro roadm-maxloss?            decimal64
                   +--ro roadm-minloss?            decimal64
                   +--ro roadm-typloss?            decimal64
                   +--ro roadm-pmin?               decimal64
                   +--ro roadm-pmax?               decimal64
                   +--ro roadm-ptyp?               decimal64
                   +--ro roadm-osnr?               decimal64
                   +--ro roadm-noise-figure?       decimal64
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:information-source-entry/tet:connectivity-matrices:
       +--ro roadm-path-impairments?   -> ../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
```

```
     tet:information-source-entry/tet:connectivity-matrices/
     tet:connectivity-matrix:
       +--ro roadm-path-impairments?   -> ../../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:te-node-attributes/tet:connectivity-matrices:
       +--ro roadm-path-impairments?   -> ../../roadm-path-impairments/
       roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:te-node-attributes/tet:connectivity-matrices/
     tet:connectivity-matrix:
       +--ro roadm-path-impairments?   -> ../../../
       roadm-path-impairments/roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:tunnel-termination-point/tet:local-link-connectivities:
       +--ro add-path-impairments?    -> ../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
       +--ro drop-path-impairments?   -> ../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:tunnel-termination-point/tet:local-link-connectivities/
     tet:local-link-connectivity:
       +--ro add-path-impairments?    -> ../../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
       +--ro drop-path-impairments?   -> ../../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
```

4. Optical Impairment Topology YANG Model

[Editor’s note: YANG code below may have to be updated before submission!]

```
   <CODE BEGINS>
   module ietf-optical-impairment-topology {
     yang-version 1.1;

     namespace "urn:ietf:params:xml"
     +":ns:yang:ietf-optical-impairment-topology";

     prefix "optical-imp-topo";

     import ietf-network {
       prefix "nw";
```

```
     }

     import ietf-network-topology {
       prefix "nt";
     }

     import ietf-te-topology {
       prefix "tet";
     }

     import ietf-layer0-types {
       prefix "layer0-types";
     }

     organization
       "IETF CCAMP Working Group";

     contact
       "Editor:   Young Lee <younglee.tx@gmail.com>
        Editor:   Haomian Zheng <zhenghaomian@huawei.com>
        Editor:   Nicola Sambo <nicosambo@gmail.com>
        Editor:   Victor Lopez <victor.lopezalvarez@telefonica.com>
        Editor:   Gabriele Galimberti <ggalimbe@cisco.com>
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        Editor:   Dieter Beller <dieter.beller@nokia.com>
        Editor:   Sergio Belotti <Sergio.belotti@nokia.com>
        Editor:   Griseri Enrico <enrico.griseri@nokia.com>
        Editor:   Gert Grammel <ggrammel@juniper.net>";

     description
       "This module contains a collection of YANG definitions for
        impairment-aware optical networks.

        Copyright (c) 2019 IETF Trust and the persons identified as
        authors of the code.  All rights reserved.

        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
        (http://trustee.ietf.org/license-info).";

     revision 2020-03-09 {
```

```
        description
          "Initial Version";
        reference
          "RFC XXXX: A Yang Data Model for Impairment-aware
           Optical Networks";
      }

      // identity

      identity modulation {
        description "base identity for modulation type";
      }

      identity QPSK {
        base modulation;
        description
          "QPSK (Quadrature Phase Shift Keying) modulation";
      }

      identity DP-QPSK {
        base modulation;
        description
          "DP-QPSK (Dual Polarization Quadrature
           Phase Shift Keying) modulation";
      }
      identity QAM8 {
        base modulation;
        description
          "8QAM (8-State Quadrature Amplitude Modulation) modulation";
      }
      identity QAM16 {
        base modulation;
        description
          "QAM16 (Quadrature Amplitude Modulation)";
      }
      identity DP-QAM8 {
        base modulation;
        description
          "DP-QAM8 (Dual Polarization Quadrature Amplitude Modulation)";
      }
      identity DC-DP-QAM8 {
        base modulation;
        description
        "DC DP-QAM8 (Dual Polarization Quadrature Amplitude Modulation)";
      }
      identity DP-QAM16 {
        base modulation;
        description
```

```
         "DP-QAM16 (Dual Polarization Quadrature Amplitude Modulation)";
     }
     identity DC-DP-QAM16 {
       base modulation;
       description
       "DC DP-QAM16 (Dual Polarization Quadrature
       Amplitude Modulation)";
     }

     identity FEC {
       description
         "Enumeration that defines the type of
          Forward Error Correction";
     }
     identity reed-solomon {
       base FEC;
         description
     "Reed-Solomon error correction";
     }
     identity hamming-code {
       base FEC;
         description
     "Hamming Code error correction";
     }
     identity golay {
       base FEC;
         description "Golay error correction";
     }

     // typedef

     typedef fiber-type {
       type enumeration {
         enum G.652 {
         description "G.652 Standard Singlemode Fiber";
         }
         enum G.654 {
           description "G.654 Cutoff Shifted Fiber";
         }
         enum G.653 {
           description "G.653 Dispersion Shifted Fiber";
         }
         enum G.655 {
           description "G.655 Non-Zero Dispersion Shifted Fiber";
         }
         enum G.656 {
           description "G.656 Non-Zero Dispersion for Wideband
                  Optical Transport";
```

```
          }
          enum G.657 {
            description "G.657 Bend-Insensitive Fiber";
          }
        }
        description
          "ITU-T based fiber-types";
      }

   /*temporary defined here for disalignment with*/
   /* ietf-layer0-types module*/

      typedef operational-mode {
        type string;
        description
          "Vendor-specific mode that guarantees
          interoperability.";
        reference "ITU-T G.698.2 (11/2018)";
      }

   // temporary defined here for disalignment with
   //ietf-layer0-types module
      typedef standard-mode {
        type string;
        description
          "ITU-T G.698.2 standard mode that guarantees
           interoperability.
           It must be an string with the following format:
           B-DScW-ytz(v) where all these attributes
           are conformant
           to the ITU-T recomendation";
        reference "ITU-T G.698.2 (11/2018)";
      }

   // temporary defined here for disalignment
   //with ietf-layer0-types module
      typedef vendor-identifier {
        type string;
        description
          "vendor identifier that uses vendor-specific mode";
        reference
          "RFC7581: Routing and Wavelength Assignment Information
           Encoding for Wavelength Switched Optical Networks";
      }

      // grouping

      grouping transponder-attributes {
```

```
      description "Configuration of an optical transponder";

      leaf-list available-modulation-types {
        type identityref {
        base modulation;
        }
        config false;
      description
        "List of modulation types the OTSi supports";
      }

      leaf configured-modulation-type {
        type identityref {
        base modulation;
        }
      config false;
        description
        "Currently configured OTSi modulation type";
      }

      leaf-list available-baud-rates {
        type uint32;
          units Bd;
        config false;
        description
          "list of available baud-rates.
           Baud-rate is the unit for
           symbol rate or modulation rate
           in symbols per second or
           pulses per second.
           It is the number of distinct symbol
           changes (signal events) made to the
           transmission medium
           per second in a digitally
           modulated signal or a line code";
      }

      leaf configured-baud-rate {
        type uint32;
        units Bd;
      config false;
        description "configured baud-rate";
      }

      leaf-list available-FEC-types {
        type identityref {
        base FEC;
        }
```

```
          config false;
          description "List determining all the available FEC";
        }

        leaf configured-FEC-type {
          type identityref {
          base FEC;
          }
          config false;
        description
          "FEC type configured for the transponder";
        }

        leaf FEC-code-rate {
          type decimal64 {
          fraction-digits 8;
          range "0..max";
          }
          config false;
          description "FEC-code-rate";
        }

        leaf FEC-threshold {
          type decimal64 {
          fraction-digits 8;
          range "0..max";
          }
          config false;
        description
            "Threshold on the BER, for which FEC
             is able to correct errors";
        }

      }

      grouping sliceable-transponder-attributes {
        description
          "Configuration of a sliceable transponder.";
        list transponder-list {
          key "carrier-id";
          config false;
          description "List of carriers";
          leaf carrier-id {
            type uint32;
            config false;
            description "Identifier of the carrier";
          }
        }
```

```
     }

     grouping optical-fiber-data {
       description
       "optical link (fiber) attributes with impairment data";
       leaf fiber-type {
         type fiber-type;
         config false;
         description "fiber-type";
       }

       leaf span-length {
         type decimal64 {
           fraction-digits 2;
         }
         units "km";
         config false;
         description "the lenght of the fiber span in km";
       }

       leaf input-power {
         type decimal64 {
           fraction-digits 2;
         }
         units "dBm";
         config false;
         description
         "Average input power level estimated at the receiver
            of the link";
       }

       leaf output-power {
         type decimal64 {
           fraction-digits 2;
         }
         units "dBm";
         description
         "Mean launched power at the transmitter of the link";
       }

       leaf pmd {
         type decimal64 {
           fraction-digits 8;
           range "0..max";
         }
         units "ps/(km)^0.5";
         config false;
         description
```

```
         "Polarization Mode Dispersion";
        }

        leaf cd {
          type decimal64 {
            fraction-digits 5;
          }
          units "ps/nm/km";
          config false;
          description
          "Cromatic Dispersion";
        }

        leaf osnr {
          type decimal64 {
            fraction-digits 5;
          }
          units "dB";
          config false;
          description
          "Optical Signal-to-Noise Ratio (OSNR) estimated
             at the receiver";
        }

        leaf sigma {
          type decimal64 {
            fraction-digits 5;
          }
          units "dB";
          config false;
          description
          "sigma in the Gausian Noise Model";
        }
      }

      grouping optical-channel-data {
      description
        "optical impairment data per channel/wavelength";
      leaf bit-rate {
        type decimal64 {
          fraction-digits 8;
            range "0..max";
        }
        units "Gbit/s";
        config false;
        description
          "Gross bit rate";
      }
```

```
       leaf BER {
       type decimal64 {
         fraction-digits 18;
               range "0..max";
       }
       config false;
         description
         "BER (Bit Error Rate)";
     }

       leaf ch-input-power {
             type decimal64 {
              fraction-digits 2;
           }
           units "dBm";
           config false;
           description
       "Per channel average input power level
             estimated at the receiver of the link";
           }

     leaf ch-pmd {
       type decimal64 {
           fraction-digits 8;
         range "0..max";
       }
       units "ps/(km)^0.5";
       config false;
       description
         "per channel Polarization Mode Dispersion";
     }

     leaf ch-cd {
       type decimal64 {
               fraction-digits 5;
       }
       units "ps/nm/km";
       config false;
             description
         "per channel Cromatic Dispersion";
     }

     leaf ch-osnr {
       type decimal64 {
         fraction-digits 5;
       }
         units "dB";
       config false;
```

```
        description
          "per channel Optical Signal-to-Noise Ratio
                (OSNR) estimated at the receiver";
       }

        leaf q-factor {
        type decimal64 {
          fraction-digits 5;
        }
        units "dB";
        config false;
          description
          "q-factor estimated at the receiver";
        }
      }

      grouping standard-mode {
        description
          "ITU-T G.698.2 standard mode that guarantees interoperability.
           It must be an string with the following format:
           B-DScW-ytz(v) where all these attributes are conformant
           to the ITU-T recomendation";

        leaf standard-mode {
          type standard-mode;
          config false;
          description
            "G.698.2 standard mode";
        }
      }

      grouping organizational-mode {
        description
          "Transponder operational mode supported by organizations or
           vendor";

        leaf operational-mode {
          type operational-mode;
          config false;
          description
            "configured organization- or vendor-specific
             application identifiers (AI) supported by the transponder";
        }

        leaf organization-identifier {
          type vendor-identifier;
          config false;
          description
```

```
         "organization identifier that uses organizational
            mode";

       }
     }

       /*
      * Identities
      */
     identity type-element {
       description
         "Base identity for element type";
     }

     identity Fiber {
       base type-element;
       description
         "Fiber element";
     }

     identity Roadm {
       base type-element;
       description
         "Roadm element";
     }

     identity Edfa {
       base type-element;
       description
         "Edfa element";
     }

     identity Concentratedloss {
       base type-element;
       description
         "Concentratedloss element";
     }

     identity type-power-mode {
       description
         "power equalization mode used within the
          OMS and its elements";
     }

     identity power-spectral-density {
       base type-power-mode;
       description
         "all elements must use power spectral density (W/Hz)";
```

```
     }

     identity channel-power {
       base type-power-mode;
       description
         "all elements must use power (dBm)";
     }

     /*
      * Groupings
      */
     grouping amplifier-params {
       description "describes parameters for an amplifier";
       container amplifier{
       description "amplifier type, operatonal parameters
                    are described";
         leaf type-variety {
           type string ;
           mandatory true ;
           description
             "String identifier of amplifier type referencing
             a specification in a separate equipment catalog";
         }
         container operational {
           description "amplifier operationnal parameters";
           leaf actual-gain {
             type decimal64 {
               fraction-digits 2;
             }
             units dB ;
         mandatory true ;
             description "..";
           }
           leaf tilt-target {
             type decimal64 {
               fraction-digits 2;
             }
             mandatory true ;
             description "..";
           }
           leaf out-voa {
             type decimal64 {
               fraction-digits 2;
             }
             units dB;
         mandatory true;
             description "..";
           }
```

```
          leaf in-voa {
            type decimal64 {
              fraction-digits 2;
            }
            units dB;
        mandatory true;
            description "..";
          }
          uses power-param;
        }
      }
    }

    grouping fiber-params {
      description
        "String identifier of fiber type referencing a
         specification in a separate equipment catalog";
      container fiber {
      description "fiber characteristics";
        leaf type-variety {
          type string ;
      mandatory true ;
          description "fiber type";
        }
        leaf length {
          type decimal64 {
            fraction-digits 2;
          }
          units km;
      mandatory true ;
      description "length of fiber";
        }
        leaf loss-coef {
          type decimal64 {
            fraction-digits 2;
          }
          units dB/km;
      mandatory true ;
      description "loss coefficient of the fiber";
        }
        leaf total-loss {
          type decimal64 {
            fraction-digits 2;
          }
          units dB;
      mandatory true ;
          description
            "includes all losses: fiber loss and conn-in and
```

```
               conn-out losses";
         }
         leaf pmd{
           type decimal64 {
             fraction-digits 2;
           }
           units sqrt(ps);
       description "pmd of the fiber";
         }
         leaf conn-in{
           type decimal64 {
             fraction-digits 2;
           }
           units dB;
       description "connector-in";
         }
         leaf conn-out{
           type decimal64 {
             fraction-digits 2;
           }
           units dB;
       description "connector-out";
         }
       }
     }



     grouping roadm-express-path {
       description "roadm express path optical impairments";

       container roadm-express-path {
         description "roadm parameters per express path";

         leaf roadm-pmd {
           type decimal64 {
             fraction-digits 8;
             range "0..max";
           }
           units "ps/(km)^0.5";
           description
             "Polarization Mode Dispersion";
         }
         leaf roadm-cd {
           type decimal64 {
             fraction-digits 5;
           }
           units "ps/nm";
```

```
          description "Chromatic Dispersion";
        }
        leaf roadm-pdl {
          type decimal64 {
            fraction-digits 2;
          }
          units dB ;
          description "Polarization dependent loss";
        }
        leaf roadm-inband-crosstalk {
          type decimal64 {
            fraction-digits 2;
          }
          units dB;
          description
            "In-band crosstalk, or coherent crosstalk, can occur in
             components that can have multiple same wavelength inputs
             with the inputs either routed to different output ports,
             or all but 1 blocked";
        }
        leaf roadm-maxloss {
          type decimal64 {
            fraction-digits 2;
          }
          units dB;
          description
            "This is the maximum expected add path loss from the
             ROADM ingress to the ROADM egress
             assuming no additional add path loss is added";
        }
      }
    }

    grouping roadm-add-path {
      description "roadm add block path optical impairments";

      container roadm-add-path {
        description "roadm optical impairment parameters
        per add path";

        leaf roadm-pmd {
          type decimal64 {
            fraction-digits 8;
            range "0..max";
          }
          units "ps";
          description
            "Polarization Mode Dispersion";
```

```
         }
         leaf roadm-cd {
           type decimal64 {
             fraction-digits 5;
           }
           units "ps/nm";
           description "Cromatic Dispersion";
         }
         leaf roadm-pdl {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description "Polarization dependent loss";
         }
         leaf roadm-inband-crosstalk {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description
             "In-band crosstalk, or coherent crosstalk,
              can occur in components that can have multiple same
              wavelength inputs,with the inputs either
              routed to different output ports,
              or all but 1 blocked.
              In the case of add path it is the total
              of the add block
              + egress WSS crosstalk contributions.";
         }
         leaf roadm-maxloss {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description
             "This is the maximum expected add path loss from
              the add/drop port input to the ROADM egress,
              assuming no additional add path loss is added.
              This is used to establish the minimum required
              transponder output power required
              to hit the ROADM egress target power
              levels and preventing
              to hit the WSS attenuation limits.
              If the add path contains an internal amplifier
              this loss value should be based
              on worst case expected amplifier gain due to
              ripple or gain uncertainty";
```

```
        }
        leaf roadm-pmax {
          type decimal64 {
            fraction-digits 2;
          }
          units dBm ;
          description
            "This is the maximum (per carrier) power level
             permitted at the add block input ports,
             that can be handled by the ROADM node.
             This may reflect either add amplifier power
             contraints or WSS adjustment limits.
             Higher power transponders would need to have
             their launch power reduced
             to this value or lower";
        }
        leaf roadm-osnr {
          type decimal64 {
            fraction-digits 5;
          }
          units "dB";
          description
            "Optical Signal-to-Noise Ratio (OSNR).
             If the add path contains the ability to adjust the
             carrier power levels into an add path amplifier
             (if present) to a target value,
             this reflects the OSNR contribution of the
             add amplifier assuming this target value is obtained.
             The worst case OSNR based on the input power and
             NF calculation method, and this value, should be used
             (if both are defined).";
        }
        leaf roadm-noise-figure {
          type decimal64 {
            fraction-digits 5;
          }
          units "dB";
          description
            "Noise Figure. If the add path contains an amplifier,
             this is the noise figure of that amplifier inferred
             to the add port.
             This permits add path OSNR calculation based
             on the input power levels to the add block
             without knowing the ROADM path losses to
             the add amplifier.";
        }
      }
    }
```

```
     grouping roadm-drop-path {
       description "roadm drop block path optical impairments";

       container roadm-drop-path {
         description "roadm optical impairment parameters
         per drop path";

         leaf roadm-pmd {
           type decimal64 {
             fraction-digits 8;
             range "0..max";
           }
           units "ps/(km)^0.5";
           description
             "Polarization Mode Dispersion";
         }
         leaf roadm-cd {
           type decimal64 {
             fraction-digits 5;
           }
           units "ps/nm";
           description "Chromatic Dispersion";
         }
         leaf roadm-pdl {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description "Polarization dependent loss";
         }
         leaf roadm-inband-crosstalk {
           type decimal64 {
             fraction-digits 2;
           }
           units dB;
           description
             "In-band crosstalk, or coherent crosstalk, can occur in
              components that can have multiple same wavelength
              inputs,with the inputs either routed to different
              output ports,or all but 1 blocked.
              In the case of drop path it is the total
              of the ingress
              to drop e.g. WSS and drop block crosstalk
              contributions.";
         }
         leaf roadm-maxloss {
           type decimal64 {
             fraction-digits 2;
```

```
           }
           units dB ;
           description
             "The net loss from the ROADM input,to the output
              of the drop block.
              If ROADM ingress to drop path includes an amplifier,
              the amplifier gain reduces the net loss.
              This is before any additional drop path attenuation
              that may be required
              due to drop amplifier power contraints.
              The max value correspond to worst case expected loss,
              including amplifier gain ripple or uncertainty.
              It is the maximum output power of the drop
              amplifier.";
         }
         leaf roadm-minloss {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description
             "The net loss from the ROADM input, to the
              output of the drop block.
              If this ROADM ingress to drop path includes
              an amplifier,the amplifier gain reduces the net loss.
              This is before any additional drop path attenuation
              that may be required due to drop amplifier power
              contraints.
              The min value correspond to best case expected loss,
              including amplifier gain ripple or uncertainty.";
         }
         leaf roadm-typloss {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           description
             "The net loss from the ROADM input,
              to the output of the drop block.
              If this ROADM ingress to drop path
              includes an amplifier,
              the amplifier gain reduces the net loss.
              This is before any additional drop path
              attenuation
              that may be required due to drop amplifier
              power contraints.
              The typ value correspond to typical case
              expected loss.";
```

```
         }
         leaf roadm-pmin {
           type decimal64 {
             fraction-digits 2;
           }
           units dBm ;
           description
             "If the drop path has additional loss
              that is added, for example,
              to hit target power levels into a
              drop path amplifier, or simply, to reduce the
              power of a "strong" carrier
              (due to ripple,for example),
              then the use of the ROADM input power levels and
              the above drop losses is not appropriate.
              This parameter corresponds to the min per
              carrier power levels
              expected at the output of the drop block.
              A detail example of the comparison using
              these parameters is
              detailed in section xxx of the document yyy.";
         }
         leaf roadm-pmax {
           type decimal64 {
             fraction-digits 2;
           }
           units dBm ;
           description
             "If the drop path has additional loss that is added,
              for example, to hit target power levels into a
              drop path amplifier,or simply,to reduce the power
              of a "strong" carrier(due to ripple,for example),
              then the use of the ROADM input power levels and the
              above drop losses is not appropriate.
              This parameter corresponds to the best case per
              carrier power levels expected at the output of the
              drop block.
              A detail example of the comparison using
              these parameters
              is detailed in section xxx of the document yyy";
         }
         leaf roadm-ptyp {
           type decimal64 {
             fraction-digits 2;
           }
           units dBm ;
           description
             "If the drop path has additional loss that is added,
```

```
              for example, to hit target power levels into a
              drop path amplifier,or simply,to reduce the
              power of a "strong" carrier(due to ripple,for example),
              then the use of the ROADM input power levels and
              the above drop losses is not appropriate.
              This parameter corresponds to the typical case
              per carrier power levels expected
              at the output of the drop block.";
         }
         leaf roadm-osnr {
           type decimal64 {
             fraction-digits 5;
           }
           units "dB";
           description
             "Optical Signal-to-Noise Ratio (OSNR).
              Expected OSNR contribution of the drop path
              amplifier(if present)
              for the case of additional drop path loss
              (before this amplifier)
              in order to hit a target power level (per carrier).
              If both, the OSNR based on the ROADM
              input power level
              (Pcarrier =
              Pref+10Log(carrier-baudrate/ref-baud) + delta-power)
              and the input inferred NF(NF.drop),
              and this OSNR value, are defined,
              the minimum value between these two should be used";
         }
         leaf roadm-noise-figure {
           type decimal64 {
             fraction-digits 5;
           }
           units "dB";
           description
             "Drop path Noise Figure.
              If the drop path contains an amplifier,
              this is the noise figure
              of that amplifier, inferred to the
              ROADM ingress port.
              This permits to determine
              amplifier OSNR contribution
              without having to specify the
              ROADM node's losses to that amplifier.
              This applies for the case of no
              additional drop path loss,
              before the amplifier, in order to reduce the power
              of the carriers to a target value";
```

```
          }
        }
      }

      grouping concentratedloss-params{
        description "concentrated loss";
        container concentratedloss{
        description "concentrated loss";
          leaf loss {
            type decimal64 {
              fraction-digits 2;
            }
            units dB ;
            description "..";
          }
        }
      }

      grouping power-param{
        description
          "optical power or PSD after the ROADM or after the out-voa";
        choice power-param {
          description
            "select the mode: channel power or power spectral density";
          case channel-power {
    /*        when "equalization-mode='channel-power'"; */
            leaf nominal-channel-power{
              type decimal64 {
                  fraction-digits 1;
              }
              units dBm ;
              description
                " Reference channel power after the ROADM or after
                the out-voa. ";
            }
          }
          case power-spectral-density{
    /*        when "equalization-mode='power-spectral-density'"; */
            leaf nominal-power-spectral-density{
              type decimal64 {
                  fraction-digits 16;
              }
              units W/Hz ;
              description
                " Reference power spectral density after
                  the ROADM or after the out-voa.
                  Typical value : 3.9 E-14, resolution 0.1nW/MHz";
            }
```

```
         }
       }
     }

     grouping oms-general-optical-params {
       description "OMS link optical parameters";
       leaf generalized-snr {
         type decimal64 {
           fraction-digits 5;
         }
         units "dB@0.1nm";
         description "generalized snr";
       }
       leaf equalization-mode{
         type identityref {
           base type-power-mode;
         }
         mandatory true;
         description "equalization mode";
       }
       uses power-param;
     }

     grouping OTSiG {
       description "OTSiG definition , representing client
        digital information stream supported by 1 or more OTSi";

       container OTSiG-container {
         config false;
         description
           "the container contains the related list of OTSi.
           The list could also be of only 1 element";
        list OTSi {
          key "OTSi-carrier-id";
          description
            "list of OTSi's under OTSi-G";
          leaf OTSi-carrier-id {
            type int16;
            description "OTSi carrier-id";
            }
          leaf OTSi-carrier-frequency {
            type decimal64 {
              fraction-digits 3;
            }
            units GHz;
            config false;
            description
              "OTSi carrier frequency";
```

```
          }
          leaf OTSi-signal-width {
            type decimal64 {
              fraction-digits 3;
            }
            units GHz;
            config false;
            description
              "OTSi signal width";
          }
          leaf channel-delta-power {
            type decimal64 {
              fraction-digits 2;
            }
            units dB;
            config false;
            description
              "optional ; delta power to ref channel
               input-power applied
              to this media channel";
          }

        }
      }  // OTSiG container
    } // OTSiG grouping

    grouping media-channel-groups {
      description "media channel groups";
      list media-channel-group {
      key "i";
        description
          "list of media channel groups";
        leaf i {
          type int16;
            description "index of media channel group member";
        }

        list media-channels {
          key "flexi-n";
          description
            "list of media channels represented as (n,m)";
          uses layer0-types:flexi-grid-channel;
          leaf OTSiG-ref {
            type leafref {
             path "/nw:networks/nw:network/nw:node/tet:te" +
                  "/tet:tunnel-termination-point" +
                  "/OTSiG-element/OTSiG-identifier" ;
```

```
             }
             description
                "Reference to the OTSiG list to get OTSiG
                 identifier of the
                 OSiG carried by this media channel
                 that reports the transient stat";
           }
           leaf OTSi-ref {
             type leafref {
               path "/nw:networks/nw:network/nw:node/tet:te" +
                   "/tet:tunnel-termination-point/"
                  +"OTSiG-element[OTSiG-identifier=current()"
                  +"/../OTSiG-ref]/"
                  + "OTSiG-container/OTSi/OTSi-carrier-id" ;
             }
             description
                "Reference to the OTSi list supporting the
                 related OTSiG" ;
           }

         } // media channels list
       } // media-channel-groups list
     } // media media-channel-groups grouping

     grouping oms-element {
       description "OMS description";
       list OMS-elements {
           key "elt-index";
           description
             "defines the spans and the amplifier blocks of
             the amplified lines";
           leaf elt-index {
             type uint16;
             description
               "ordered list of Index of OMS element
               (whether it's a Fiber, an EDFA or a
   Concentratedloss)";
           }
           leaf uid {
             type string;
             description
               "unique id of the element if it exists";
           }
           leaf type {
             type identityref {
                base type-element;
             }
         mandatory true;
```

```
         description "element type";
           }

           container element {
             description "element of the list of elements of the OMS";
             choice element {
           description "OMS element type";
               case amplifier {
    /*             when "type = 'Edfa'"; */
                 uses amplifier-params ;
               }
               case fiber {
   /*              when "type = 'Fiber'"; */
                 uses fiber-params ;
               }
               case concentratedloss {
   /*             when "type = 'Concentratedloss'"; */
                 uses concentratedloss-params ;
               }
             }
           }
       }
     }

   /* Data nodes */

     augment "/nw:networks/nw:network/nw:network-types"
      + "/tet:te-topology" {
      description "optical-impairment topology augmented";
      container optical-impairment-topology {
        presence "indicates an impairment-aware topology of
        optical networks";
        description
        "Container to identify impairment-aware topology type";
      }
     }

     augment "/nw:networks/nw:network/nt:link/tet:te"
      + "/tet:te-link-attributes"   {
      when "/nw:networks/nw:network/nw:network-types"
       +"/tet:te-topology/"
       +"optical-imp-topo:optical-impairment-topology" {
       description
         "This augment is only valid for Optical Impairment.";
      }
      description "Optical Link augmentation for impairment data.";
      container OMS-attributes {
          config false;
```

```
          description "OMS attributes";
        uses oms-general-optical-params;
        uses media-channel-groups;
        uses oms-element;
        }
    }

    augment "/nw:networks/nw:network/nw:node/tet:te"
     + "/tet:tunnel-termination-point" {
     when "/nw:networks/nw:network/nw:network-types"
      +"/tet:te-topology/optical-imp-topo:optical-impairment-topology"{
      description
        "This augment is only valid for Impairment with non-sliceable
         transponder model";
     }
     description
       "Tunnel termination point augmentation for non-sliceable
        transponder model.";

       list OTSiG-element {
           key "OTSiG-identifier";
           config false;
           description
           "the list of possible OTSiG representing client digital
            stream";

           leaf OTSiG-identifier {
              type int16;
               description "index of OTSiG element";
           }
           uses OTSiG;
       }

       list transponders-list {
           key "transponder-id";
       config false;
           description "list of transponders";
           leaf transponder-id {
         type uint32;
         description "transponder identifier";
           }

           choice mode {
               description "standard mode, organizational mode or
                explicit mode";

               case G.692.2 {
                 uses standard-mode;
```

```
                }

                case organizational-mode {
                  uses organizational-mode;
                }

                case explicit-mode {
                  uses transponder-attributes;
                }
            }

            leaf power {
              type int32;
              units "dBm";
              config false;
              description "per channel power";
            }

            leaf power-min {
              type int32;
              units "dBm";
              config false;
              description "minimum power of the transponder";
            }
            leaf power-max {
              type int32;
              units "dBm";
              config false;
              description "maximum power of the transponder";
            }
       }
      }

      augment "/nw:networks/nw:network/nw:node/tet:te"
       + "/tet:tunnel-termination-point" {
       when "/nw:networks/nw:network/nw:network-types"
        +"/tet:te-topology/"
        + "optical-imp-topo:optical-impairment-topology" {
        description
          "This augment is only valid for optical impairment
           with sliceable transponder model";
       }
       description
         "Tunnel termination point augmentation for sliceable
          transponder model.";
       uses sliceable-transponder-attributes;
      }
```

```
     augment "/nw:networks/nw:network/nw:node/tet:te"
           + "/tet:te-node-attributes" {
       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology"
          + "/optical-imp-topo:optical-impairment-topology" {

         description
           "This augment is only valid for Optical Impairment
           topology";
       }
       description
         "node attributes augmentantion for optical-impairment ROADM
          node";

       list roadm-path-impairments {
         key "roadm-path-impairments-id";
         config false;
         description "list of set of optical impairments related
         to ROADM ";

         leaf roadm-path-impairments-id {
           type uint32;
           description "index of the ROADM path-impairment list";
         }
         choice impairment-type {
           description "type path impairment";
           case roadm-express-path {
             uses roadm-express-path;
           }
           case roadm-add-path {
             uses roadm-add-path;
           }
           case roadm-drop-path {
             uses roadm-drop-path;
           }
         }
       } // list path impairments
     } // augmentation for optical-impairment ROADM

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:information-source-entry/tet:connectivity-matrices"{
       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for Optical Impairment
           topology ";
       }
```

```
        description
          "Augment default TE node connectivity matrix information
          source.";

        leaf roadm-path-impairments {
          type leafref {
            path "../../../tet:te-node-attributes/"
            + "roadm-path-impairments/roadm-path-impairments-id";
          }
          description "pointer to the list set of ROADM optical
          impairments";
        }
      } // augmentation connectivity-matrices information-source

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:information-source-entry/tet:connectivity-matrices/"
            + "tet:connectivity-matrix" {
        when "/nw:networks/nw:network/nw:network-types"
           + "/tet:te-topology/"
           + "optical-imp-topo:optical-impairment-topology" {
          description
            "This augment is only valid for Optical Impairment
             topology ";
        }

        description
          "Augment TE node connectivity matrix entry information
          source.";

        leaf roadm-path-impairments {
          type leafref {
            path "../../../../tet:te-node-attributes/"
            + "roadm-path-impairments/roadm-path-impairments-id";
          }
          description "pointer to the list set of ROADM optical
          impairments";
        }
      } // augmentation connectivity-matrix information-source

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:te-node-attributes/tet:connectivity-matrices" {
        when "/nw:networks/nw:network/nw:network-types"
           + "/tet:te-topology/"
           + "optical-imp-topo:optical-impairment-topology" {
          description
            "This augment is only valid for Optical Impairment
            topology ";
        }
```

```
        description
          "Augment default TE node connectivity matrix.";
        leaf roadm-path-impairments {
          type leafref {
            path "../../roadm-path-impairments/"
            + "roadm-path-impairments-id";
          }
          config false; /*the identifier in the list */
           /*"roadm-path-impairments" of ROADM optical impairment*/
                        /*is read-only as the rest of attributes*/
          description "pointer to the list set of ROADM optical
          impairments";
        }
      } // augmentation connectivity-matrices

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:te-node-attributes/"
            + "tet:connectivity-matrices/tet:connectivity-matrix" {
        when "/nw:networks/nw:network/nw:network-types"
           + "/tet:te-topology/"
           + "optical-imp-topo:optical-impairment-topology" {
          description
            "This augment is only valid for
            Optical Impairment topology ";
        }

        description
          "Augment TE node connectivity matrix entry.";

        leaf roadm-path-impairments {
          type leafref {
            path "../../../roadm-path-impairments/"
            + "roadm-path-impairments-id";
          }
          config false;
          description "pointer to the list set of ROADM optical
           impairments";
        }
      } // augmentation connectivity-matrix

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

        when "/nw:networks/nw:network/nw:network-types"
           + "/tet:te-topology/"
           + "optical-imp-topo:optical-impairment-topology" {
          description
```

```
         "This augment is only valid for Optical Impairment topology ";
       }

       description
         "Augment default TTP LLC.";
       leaf add-path-impairments {
         type leafref {
           path "../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id" ;
         }
         config false;
         description "pointer to the list set of ROADM optical
          impairments";
       }
       leaf drop-path-impairments {
         type leafref {
           path "../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id" ;
         }
         config false;
         description "pointer to the list set of ROADM
         optical impairments";
       }
     } // augmentation local-link-connectivities

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

       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for
            Optical Impairment topology ";
       }

       description
         "Augment TTP LLC entry.";
       leaf add-path-impairments {
         type leafref {
           path "../../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id" ;
         }
         config false;
         description "pointer to the list set of ROADM optical
          impairments";
```

```
        }
        leaf drop-path-impairments {
          type leafref {
            path "../../../../tet:te-node-attributes/"
            + "roadm-path-impairments/roadm-path-impairments-id" ;
          }
          config false;
          description "pointer to the list set of ROADM optical
          impairments";
        }
      } // augmentation local-link-connectivity
    }

    <CODE ENDS>
```

5. 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 [RFC8341] 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 read-only; however, these data nodes may be considered sensitive or vulnerable in some network environments (TBD).

6. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```
--------------------------------------------------------------------
URI: urn:ietf:params:xml:ns:yang:ietf-optical-impairment-topology
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-optical-impairment-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-optical-impairment-
topology
prefix:    optical-imp-topo
reference: RFC XXXX (TDB)
--------------------------------------------------------------------
```

7. Acknowledgments

We thank Daniele Ceccarelli and Oscar G. De Dios for useful discussions and motivation for this work.

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CCAMP Working Group
Internet-Draft
Intended status: Standards Track
Expires: March 25, 2021

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September 21, 2020

A YANG Data Model for Optical Transport Network Topology
draft-ietf-ccamp-otn-topo-yang-11

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.

Status of This Memo

Table of Contents

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):

- o To obtain a whole view of the network topology information of its interest;

- o To receive notifications with regard to the information change of the OTN topology;

- o 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].

Other topology models for Optical network technologies, including fixed Dense Wavelength Switched Optical Network (WSON) and flexible optical networks (a.k.a., flexi-grid networks), are covered in [I-D.ietf-ccamp-wson-yang] and [I-D.ietf-ccamp-flexigrid-yang], respectively.

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.

- 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.
- o Some of the key terms used in this document are listed as follow.
- o TS: Tributary Slot.
- o TSG: Tributary Slot Granularity.
- o 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 respectively augment the OTN attributes, TE bandwidth and TE label. Generic groupings defined in [I-D.ietf-ccamp-layer1-types] is reused as well in this document. [RFC8345] describes a network topology model and provide the fundamental model for [RFC8795]. However, this work is not directly augmenting [RFC8345].

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.

For different order of ODU in OTN technology, the te-bandwidth is augmented to allow specifying the type of ODU container and the number a link can support per priority level. For example, for a ODU3 link, it may advertise 32*ODU0, 16*ODU1, 4*ODU2 available, or multiple ODUflex, assuming only a single priority level is supported. If one of ODU2 resource is taken to establish a ODU path, then the availability of this ODU link is updated as 24*ODU0, 12*ODU1, 3*ODU2, or multiple ODUflex available. If there are equipment hardware limitations, then a subset of potential ODU type SHALL be advertised. For instance, an ODU3 link may only support 4*ODU2.

Note the model in this document re-uses some typedefs, identities and groupings defined in ietf-layer1-types, which is specified in [I-D.ietf-ccamp-layer1-types].

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

3.2. 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 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 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 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 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
   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
   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 tsg?       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 tsg?       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 tsg?       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 tsg?       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 tsg?       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 tsg?       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 tsg?       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@2020-09-21.yang"
module ietf-otn-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-otn-topology";
  prefix "otntopo";

  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).

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

        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 2020-09-21 {
       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
     }
```

```
    /*
     * Groupings
     */

     grouping otn-link-attributes {
       description "link attributes for OTN";

       leaf tsg {
         type identityref {
           base l1-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";
       }
     }

     grouping otn-tp-attributes {
       description "tp attributes for OTN";

       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 l1-types:client-signal;
           }
           description
             "List of client signal types supported by the LTP.";
         }
       }
     }

    /*
     * 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 newtork";
     }

     augment "/nw:networks/nw:network/nt:link/tet:te/"
           + "tet:te-link-attributes" {
       when "../../../nw:network-types/tet:te-topology/"
          + "otntopo:otn-topology" {
         description "Augment only for otn network.";
       }
       description "Augment link configuration";
       uses otn-link-attributes;
     }

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

     /*
      * 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/"
          + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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 l1-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 l1-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 l1-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 l1-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/"
         + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo:otn-topology" {
         description
           "Augmentation parameters apply only for networks with
            OTN topology type.";
       }
       description
         "Augment TE label range information for the TE link.";
       uses l1-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/"
          + "otntopo: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 l1-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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
```

```
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
       + "otntopo: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 l1-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/"
       + "otntopo: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 l1-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/"
       + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
        + "otntopo: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 l1-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/"
        + "otntopo: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 l1-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/"
        + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
         + "otntopo: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 l1-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/"
         + "otntopo: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 l1-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/"
         + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-types:otn-label-hop;
        }
      }

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

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            + "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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
           + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
```

```
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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/"
          + "otntopo: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/"
          + "otntopo: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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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/"
          + "otntopo: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 l1-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 l1-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 l1-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 l1-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 l1-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 l1-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:       otntopo
   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. These are the subtrees and data nodes and their sensitivity/vulnerability:

/nw:networks/nw:network/nw:network-types/tet:te-topology
/nw:networks/nw:network/nt:link/tet:te/tet:te-link-attributes
/nw:networks/nw:network/nw:node/nt:termination-point/tet:te
/nw:networks/nw:network/.../tet:te-bandwidth/tet:technology
/nw:networks/nw:network/nw:node/tet:te/.../tet:label-restriction
/nw:networks/nw:network/nw:node/.../tet:te-label/tet:technology
Editors note: we are using simplified description by folding similar branches to avoid repetation.

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:

Editors note: Currently there is no such data nodes, temporarily kept for review.

7. Acknowledgements

We would like to thank Igor Bryskin, Zhe Liu, Zheyu Fan and Daniele Ceccarelli for their comments and discussions.

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OTN Tunnel YANG Model
draft-ietf-ccamp-otn-tunnel-model-11

Abstract

This document describes the YANG data model for OTN Tunnels.

Status of This Memo

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Table of Contents

1. Introduction

OTN transport networks, specified in [ITU-Tg709], can carry various types of client signals. In many cases, the client signal is carried over an OTN tunnel across connected domains in a multi-domain network.

This document provides YANG model for creating OTN tunnel. The model augments the TE Tunnel model.

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 [RFC8340]. 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.

o More OTN specific terms can be found in [I-D.ietf-ccamp-otn-topo-yang].

3. OTN Tunnel Model Description

3.1. Overview of OTN Tunnel Model

The OTN tunnel model is using TE tunnel [I-D.ietf-teas-yang-te] as a basic model and augment to the TE tunnel with OTN-specific parameters, including the bandwidth information and label information. It is also worth noting that the OTN tunnel provisioning is usually based on the OTN topology. Therefore the OTN tunnel model is usually used together with OTN topology model specified in [I-D.ietf-ccamp-otn-topo-yang]. The OTN tunnel model also imports a few type modules, including ietf-layer1-types, ietf-te-types and ietf-inet-types. The OTN-specific attributes, such as Tributary Slot (TS), Tributary Port Number (TPN), are specified in the module ietf-layer1-types in [I-D.ietf-ccamp-layer1-types] and used in this document.

More scenarios and model applications can be found in [I-D.ietf-ccamp-transport-nbi-app-statement] and [I-D.ietf-teas-actn-yang]. The current model is following the YANG language specification as [RFC7950], and the corresponding protocol is recommended to be Netconf protocol in [RFC6241] or RESTconf protocol in [RFC8040].

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

3.2. OTN-specific Parameters in Tunnel Model

OTN specific parameters have been augmenting to the TE tunnel models. The attributes on both of the source and destination need to be configured when setting up the tunnel. Typical parameters, including client signal, TPN, TSG and corresponding tributary slot information, are required in the OTN tunnel model. These parameters are consistent with the framework in [RFC7062], and the specification in [RFC7138] and [RFC7139].

The OTN bandwidth information has been augmenting to various sections of TE tunnel models, including tunnel bandwidth, primary path bandwidth and so on. The OTN label information has been augmenting to label hop of a group of routing objects and also LSPs.

4. OTN Tunnel YANG Tree

```
   module: ietf-otn-tunnel
     augment /te:te/te:tunnels/te:tunnel:
       +--rw src-client-signal?   identityref
       +--rw dst-client-signal?   identityref
     augment /te:te/te:globals/te:named-path-constraints
               /te:named-path-constraint/te:te-bandwidth
               /te:technology:
       +--:(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?                  l1-types:gfp-k
             +--:(flexe-client)
             |  +--rw flexe-client
             |          l1-types:flexe-client-rate
             +--:(flexe-aware)
             |  +--rw flexe-aware-n           uint16
             +--:(packet)
                +--rw opuflex-payload-rate    uint64
     augment /te:te/te:tunnels/te:tunnel/te:te-bandwidth
               /te:technology:
       +--:(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?                  l1-types:gfp-k
             +--:(flexe-client)
             |  +--rw flexe-client
             |          l1-types:flexe-client-rate
             +--:(flexe-aware)
             |  +--rw flexe-aware-n           uint16
             +--:(packet)
                +--rw opuflex-payload-rate    uint64
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:te-bandwidth
```

```
              /te:technology:
       +--:(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?                  l1-types:gfp-k
             +--:(flexe-client)
             |  +--rw flexe-client
             |          l1-types:flexe-client-rate
             +--:(flexe-aware)
             |  +--rw flexe-aware-n           uint16
             +--:(packet)
                +--rw opuflex-payload-rate    uint64
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:te-bandwidth/te:technology:
       +--:(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?                  l1-types:gfp-k
             +--:(flexe-client)
             |  +--rw flexe-client
             |          l1-types:flexe-client-rate
             +--:(flexe-aware)
             |  +--rw flexe-aware-n           uint16
             +--:(packet)
                +--rw opuflex-payload-rate    uint64
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:te-bandwidth
               /te:technology:
       +--:(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?                   l1-types:gfp-k
             +--:(flexe-client)
             |  +--rw flexe-client
             |          l1-types:flexe-client-rate
             +--:(flexe-aware)
             |  +--rw flexe-aware-n            uint16
             +--:(packet)
                +--rw opuflex-payload-rate    uint64
  augment /te:te/te:globals/te:named-path-constraints
            /te:named-path-constraint
            /te:explicit-route-objects-always
            /te:route-object-exclude-always/te:type/te:label
            /te:label-hop/te:te-label/te:technology:
    +--:(otn)
       +--rw otn-tpn?   l1-types:otn-tpn
       +--rw tsg?       identityref
       +--rw ts-list?   string
  augment /te:te/te:globals/te:named-path-constraints
            /te:named-path-constraint
            /te:explicit-route-objects-always
            /te:route-object-include-exclude/te:type
            /te:label/te:label-hop/te:te-label
            /te:technology:
    +--:(otn)
       +--rw otn-tpn?   l1-types:otn-tpn
       +--rw tsg?       identityref
       +--rw ts-list?   string
  augment /te:te/te:globals/te:named-path-constraints
            /te:named-path-constraint/te:path-in-segment
            /te:label-restrictions/te:label-restriction:
    +--rw range-type?      l1-types:otn-label-range-type
    +--rw tsg?             identityref
    +--rw odu-type-list*   identityref
    +--rw priority?        uint8
  augment /te:te/te:globals/te:named-path-constraints
            /te:named-path-constraint/te:path-in-segment
            /te:label-restrictions/te:label-restriction
            /te:label-start/te:te-label/te:technology:
    +--:(otn)
       +--rw (range-type)?
          +--:(trib-port)
          |  +--rw otn-tpn?   l1-types:otn-tpn
          +--:(trib-slot)
             +--rw otn-ts?    l1-types:otn-ts
  augment /te:te/te:globals/te:named-path-constraints
            /te:named-path-constraint/te:path-in-segment
```

```
               /te:label-restrictions/te:label-restriction
               /te:label-end/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:globals/te:named-path-constraints
               /te:named-path-constraint/te:path-out-segment
               /te:label-restrictions/te:label-restriction:
       +--rw range-type?      l1-types:otn-label-range-type
       +--rw tsg?             identityref
       +--rw odu-type-list*   identityref
       +--rw priority?        uint8
     augment /te:te/te:globals/te:named-path-constraints
               /te:named-path-constraint/te:path-out-segment
               /te:label-restrictions/te:label-restriction
               /te:label-start/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:globals/te:named-path-constraints
               /te:named-path-constraint/te:path-out-segment
               /te:label-restrictions/te:label-restriction
               /te:label-end/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:optimizations
               /te:algorithm/te:metric/te:optimization-metric
               /te:explicit-route-exclude-objects
               /te:route-object-exclude-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:optimizations
               /te:algorithm/te:metric/te:optimization-metric
```

```
               /te:explicit-route-include-objects
               /te:route-object-include-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
     +--:(otn)
        +--rw otn-tpn?   l1-types:otn-tpn
        +--rw tsg?       identityref
        +--rw ts-list?   string
   augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
             /te:p2p-primary-path
             /te:explicit-route-objects-always
             /te:route-object-exclude-always/te:type/te:label
             /te:label-hop/te:te-label/te:technology:
     +--:(otn)
        +--rw otn-tpn?   l1-types:otn-tpn
        +--rw tsg?       identityref
        +--rw ts-list?   string
   augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
             /te:p2p-primary-path
             /te:explicit-route-objects-always
             /te:route-object-include-exclude/te:type
             /te:label/te:label-hop/te:te-label
             /te:technology:
     +--:(otn)
        +--rw otn-tpn?   l1-types:otn-tpn
        +--rw tsg?       identityref
        +--rw ts-list?   string
   augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
             /te:p2p-primary-path/te:path-in-segment
             /te:label-restrictions/te:label-restriction:
     +--rw range-type?      l1-types:otn-label-range-type
     +--rw tsg?             identityref
     +--rw odu-type-list*   identityref
     +--rw priority?        uint8
   augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
             /te:p2p-primary-path/te:path-in-segment
             /te:label-restrictions/te:label-restriction
             /te:label-start/te:te-label/te:technology:
     +--:(otn)
        +--rw (range-type)?
           +--:(trib-port)
           |  +--rw otn-tpn?   l1-types:otn-tpn
           +--:(trib-slot)
              +--rw otn-ts?    l1-types:otn-ts
   augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
             /te:p2p-primary-path/te:path-in-segment
             /te:label-restrictions/te:label-restriction
             /te:label-end/te:te-label/te:technology:
     +--:(otn)
```

```
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
    augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
              /te:p2p-primary-path/te:path-out-segment
              /te:label-restrictions/te:label-restriction:
      +--rw range-type?      l1-types:otn-label-range-type
      +--rw tsg?             identityref
      +--rw odu-type-list*   identityref
      +--rw priority?        uint8
    augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
              /te:p2p-primary-path/te:path-out-segment
              /te:label-restrictions/te:label-restriction
              /te:label-start/te:te-label/te:technology:
      +--:(otn)
         +--rw (range-type)?
            +--:(trib-port)
            |  +--rw otn-tpn?   l1-types:otn-tpn
            +--:(trib-slot)
               +--rw otn-ts?    l1-types:otn-ts
    augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
              /te:p2p-primary-path/te:path-out-segment
              /te:label-restrictions/te:label-restriction
              /te:label-end/te:te-label/te:technology:
      +--:(otn)
         +--rw (range-type)?
            +--:(trib-port)
            |  +--rw otn-tpn?   l1-types:otn-tpn
            +--:(trib-slot)
               +--rw otn-ts?    l1-types:otn-ts
    augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
              /te:p2p-primary-path
              /te:computed-paths-properties
              /te:computed-path-properties/te:path-properties
              /te:path-route-objects
              /te:path-computed-route-object/te:type/te:label
              /te:label-hop/te:te-label/te:technology:
      +--:(otn)
         +--ro otn-tpn?   l1-types:otn-tpn
         +--ro tsg?       identityref
         +--ro ts-list?   string
    augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
              /te:p2p-primary-path/te:lsps/te:lsp
              /te:lsp-record-route-information
              /te:lsp-record-route-information/te:type
              /te:label/te:label-hop/te:te-label
```

```
               /te:technology:
        +--:(otn)
           +--ro otn-tpn?   l1-types:otn-tpn
           +--ro tsg?       identityref
           +--ro ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:lsps/te:lsp
               /te:path-properties/te:path-route-objects
               /te:path-computed-route-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
        +--:(otn)
           +--ro otn-tpn?   l1-types:otn-tpn
           +--ro tsg?       identityref
           +--ro ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:optimizations/te:algorithm/te:metric
               /te:optimization-metric
               /te:explicit-route-exclude-objects
               /te:route-object-exclude-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
        +--:(otn)
           +--rw otn-tpn?   l1-types:otn-tpn
           +--rw tsg?       identityref
           +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:optimizations/te:algorithm/te:metric
               /te:optimization-metric
               /te:explicit-route-include-objects
               /te:route-object-include-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
        +--:(otn)
           +--rw otn-tpn?   l1-types:otn-tpn
           +--rw tsg?       identityref
           +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:explicit-route-objects-always
               /te:route-object-exclude-always/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
        +--:(otn)
           +--rw otn-tpn?   l1-types:otn-tpn
           +--rw tsg?       identityref
           +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:explicit-route-objects-always
```

```
               /te:route-object-include-exclude/te:type
               /te:label/te:label-hop/te:te-label
               /te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:path-in-segment/te:label-restrictions
               /te:label-restriction:
       +--rw range-type?      l1-types:otn-label-range-type
       +--rw tsg?             identityref
       +--rw odu-type-list*   identityref
       +--rw priority?        uint8
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:path-in-segment/te:label-restrictions
               /te:label-restriction/te:label-start/te:te-label
               /te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:path-in-segment/te:label-restrictions
               /te:label-restriction/te:label-end/te:te-label
               /te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:path-out-segment/te:label-restrictions
               /te:label-restriction:
       +--rw range-type?      l1-types:otn-label-range-type
       +--rw tsg?             identityref
       +--rw odu-type-list*   identityref
       +--rw priority?        uint8
     augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
               /te:p2p-primary-path/te:p2p-primary-reverse-path
               /te:path-out-segment/te:label-restrictions
```

```
                /te:label-restriction/te:label-start/te:te-label
                /te:technology:
         +--:(otn)
            +--rw (range-type)?
               +--:(trib-port)
               |  +--rw otn-tpn?   l1-types:otn-tpn
               +--:(trib-slot)
                  +--rw otn-ts?    l1-types:otn-ts
       augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
                /te:p2p-primary-path/te:p2p-primary-reverse-path
                /te:path-out-segment/te:label-restrictions
                /te:label-restriction/te:label-end/te:te-label
                /te:technology:
         +--:(otn)
            +--rw (range-type)?
               +--:(trib-port)
               |  +--rw otn-tpn?   l1-types:otn-tpn
               +--:(trib-slot)
                  +--rw otn-ts?    l1-types:otn-ts
       augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
                /te:p2p-primary-path/te:p2p-primary-reverse-path
                /te:computed-paths-properties
                /te:computed-path-properties/te:path-properties
                /te:path-route-objects
                /te:path-computed-route-object/te:type/te:label
                /te:label-hop/te:te-label/te:technology:
         +--:(otn)
            +--ro otn-tpn?   l1-types:otn-tpn
            +--ro tsg?       identityref
            +--ro ts-list?   string
       augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
                /te:p2p-primary-path/te:p2p-primary-reverse-path
                /te:lsps/te:lsp/te:lsp-record-route-information
                /te:lsp-record-route-information/te:type
                /te:label/te:label-hop/te:te-label
                /te:technology:
         +--:(otn)
            +--ro otn-tpn?   l1-types:otn-tpn
            +--ro tsg?       identityref
            +--ro ts-list?   string
       augment /te:te/te:tunnels/te:tunnel/te:p2p-primary-paths
                /te:p2p-primary-path/te:p2p-primary-reverse-path
                /te:lsps/te:lsp/te:path-properties
                /te:path-route-objects
                /te:path-computed-route-object/te:type/te:label
                /te:label-hop/te:te-label/te:technology:
         +--:(otn)
            +--ro otn-tpn?   l1-types:otn-tpn
```

```
          +--ro tsg?       identityref
          +--ro ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:optimizations
               /te:algorithm/te:metric/te:optimization-metric
               /te:explicit-route-exclude-objects
               /te:route-object-exclude-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:optimizations
               /te:algorithm/te:metric/te:optimization-metric
               /te:explicit-route-include-objects
               /te:route-object-include-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path
               /te:explicit-route-objects-always
               /te:route-object-exclude-always/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path
               /te:explicit-route-objects-always
               /te:route-object-include-exclude/te:type
               /te:label/te:label-hop/te:te-label
               /te:technology:
       +--:(otn)
          +--rw otn-tpn?   l1-types:otn-tpn
          +--rw tsg?       identityref
          +--rw ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-in-segment
               /te:label-restrictions/te:label-restriction:
       +--rw range-type?      l1-types:otn-label-range-type
       +--rw tsg?             identityref
       +--rw odu-type-list*   identityref
       +--rw priority?        uint8
```

```
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-in-segment
               /te:label-restrictions/te:label-restriction
               /te:label-start/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-in-segment
               /te:label-restrictions/te:label-restriction
               /te:label-end/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-out-segment
               /te:label-restrictions/te:label-restriction:
       +--rw range-type?      l1-types:otn-label-range-type
       +--rw tsg?             identityref
       +--rw odu-type-list*   identityref
       +--rw priority?        uint8
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-out-segment
               /te:label-restrictions/te:label-restriction
               /te:label-start/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:path-out-segment
               /te:label-restrictions/te:label-restriction
               /te:label-end/te:te-label/te:technology:
       +--:(otn)
          +--rw (range-type)?
             +--:(trib-port)
             |  +--rw otn-tpn?   l1-types:otn-tpn
             +--:(trib-slot)
                +--rw otn-ts?    l1-types:otn-ts
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
```

```
               /te:p2p-secondary-path
               /te:computed-paths-properties
               /te:computed-path-properties/te:path-properties
               /te:path-route-objects
               /te:path-computed-route-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--ro otn-tpn?   l1-types:otn-tpn
          +--ro tsg?       identityref
          +--ro ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:lsps/te:lsp
               /te:lsp-record-route-information
               /te:lsp-record-route-information/te:type
               /te:label/te:label-hop/te:te-label
               /te:technology:
       +--:(otn)
          +--ro otn-tpn?   l1-types:otn-tpn
          +--ro tsg?       identityref
          +--ro ts-list?   string
     augment /te:te/te:tunnels/te:tunnel/te:p2p-secondary-paths
               /te:p2p-secondary-path/te:lsps/te:lsp
               /te:path-properties/te:path-route-objects
               /te:path-computed-route-object/te:type/te:label
               /te:label-hop/te:te-label/te:technology:
       +--:(otn)
          +--ro otn-tpn?   l1-types:otn-tpn
          +--ro tsg?       identityref
          +--ro ts-list?   string
     augment /te:te/te:lsps-state/te:lsp
               /te:lsp-record-route-information
               /te:lsp-record-route-information/te:type
               /te:label/te:label-hop/te:te-label
               /te:technology:
       +--:(otn)
          +--ro otn-tpn?   l1-types:otn-tpn
          +--ro tsg?       identityref
          +--ro ts-list?   string
```

5. OTN Tunnel YANG Code

```
  <CODE BEGINS>file "ietf-otn-tunnel@2020-03-09.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";
      reference
      "I-D.ietf-teas-yang-te: A YANG Data Model for Traffic Engineering
      Tunnels and Interfaces. ";
    }

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

       Editor: Victor Lopez
               <mailto:victor.lopezalvarez@telefonica.com>

       Editor: Yunbin Xu
               <mailto:xuyunbin@ritt.cn>";

    description
      "This module defines a model for OTN Tunnel Services.
      The model fully conforms to the Network Management
      Datastore Architecture (NMDA).

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

      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 "2020-03-09" {
      description
        "Initial Revision";
      reference
        "RFC XXXX: OTN Tunnel YANG Model";
      // RFC Ed.: replace XXXX with actual RFC number, update date
      // information and remove this note
    }

   /*
    * Groupings
    */

    grouping otn-tunnel-attributes {
      description "Parameters for OTN tunnel";

      leaf src-client-signal {
        type identityref {
          base l1-types:client-signal;
        }
        description
          "Client signal at the source endpoint of the tunnel. ";
      }

      leaf dst-client-signal {
        type identityref {
          base l1-types:client-signal;
        }
        description
          "Client signal at the destination endpoint of the tunnel";
      }

   }

   /*
    * Data nodes
    */

    augment "/te:te/te:tunnels/te:tunnel" {
      description
        "Augment with additional parameters required for OTN service";
```

```
      uses otn-tunnel-attributes;
    }

    /*
     * Augment TE bandwidth
     */

           /* Augment bandwidth of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/"
          + "te:te-bandwidth/te:technology" {
      description "OTN bandwidth.";
      case otn {
        uses l1-types:otn-path-bandwidth;
      }
    }

    /* Augment bandwdith of tunnel */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:te-bandwidth/te:technology" {
      description "OTN bandwidth.";
      case otn {
        uses l1-types:otn-path-bandwidth;
      }
    }

    /* Augment bandwidth of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:te-bandwidth/te:technology" {
      description "OTN bandwidth.";
      case otn {
        uses l1-types:otn-path-bandwidth;
      }
    }

    /* Augment bandwidth of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:te-bandwidth/te:technology" {
      description "OTN bandwidth.";
      case otn {
        uses l1-types:otn-path-bandwidth;
      }
    }

    /* Augment bandwidth of secondary path */
```

```
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:te-bandwidth/te:technology" {
      description "OTN bandwidth.";
      case otn {
        uses l1-types:otn-path-bandwidth;
      }
    }

    /*
     * Augment TE label.
     */

    /* Augment label hop of route-object-exclude-always
     * of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:explicit-route-objects-always/"
          + "te:route-object-exclude-always/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-object-include-exclude
     * of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:explicit-route-objects-always/"
          + "te:route-object-include-exclude/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-in-segment of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-in-segment/"
          + "te:label-restrictions/te:label-restriction"  {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-in-segment of named-path-constraints */
```

```
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-in-segment/"
          + "te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-in-segment of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-in-segment/"
          + "te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-out-segment of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-out-segment/"
          + "te:label-restrictions/"
          + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }
    /* Augment label restrictions start for the forwarding direction
     * of path-out-segment of named-path-constraints */
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-out-segment/"
          + "te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-out-segment of named-path-constraints */
```

```
    augment "/te:te/te:globals/te:named-path-constraints/"
          + "te:named-path-constraint/te:path-out-segment/"
          + "te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label hop of route-exclude of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-exclude-objects/"
          + "te:route-object-exclude-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-include of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-include-objects/"
          + "te:route-object-include-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-object-exclude-always of
     * primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-exclude-always/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {

        uses l1-types:otn-label-hop;
```

```
      }
    }

    /* Augment label hop of route-object-include-exclude of
     * primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-include-exclude/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-in-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-in-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-in-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
```

```
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions for the forwarding direction of
     * path-out-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-out-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {

      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-out-segment of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label hop of path-route of primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:computed-paths-properties/"
          + "te:computed-path-properties/te:path-properties/"
          + "te:path-route-objects/te:path-computed-route-object/"
          + "te:type/te:label/"
```

```
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of record-route of primary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:lsps/te:lsp/te:lsp-record-route-information/"
          + "te:lsp-record-route-information/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of path-route of primary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:lsps/te:lsp/te:path-properties/"
          + "te:path-route-objects/te:path-computed-route-object/"
          + "te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-exclude of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-exclude-objects/"
          + "te:route-object-exclude-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-include of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
```

```
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-include-objects/"
          + "te:route-object-include-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-object-exclude-always of
     * reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-exclude-always/"
          + "te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-object-include-exclude of
     * reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-include-exclude/"
          + "te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-in-segment of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:path-in-segment/te:label-restrictions/"
```

```
         + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-in-segment of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-in-segment of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-out-segment of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-out-segment of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
```

```
          + "te:p2p-primary-reverse-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-out-segment of reverse primary path */

    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label hop of path-route of reverse primary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:computed-paths-properties/te:computed-path-properties/"
          + "te:path-properties/te:path-route-objects/"
          + "te:path-computed-route-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of record-route of reverse primary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:lsps/te:lsp/te:lsp-record-route-information/"
          + "te:lsp-record-route-information/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
```

```
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of path-route of reverse primary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-primary-paths/te:p2p-primary-path/"
          + "te:p2p-primary-reverse-path/"
          + "te:lsps/te:lsp/te:path-properties/"
          + "te:path-route-objects/te:path-computed-route-object/"
          + "te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-exclude of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-exclude-objects/"
          + "te:route-object-exclude-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {

      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-include of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:optimizations/te:algorithm/te:metric/"
          + "te:optimization-metric/te:explicit-route-include-objects/"
          + "te:route-object-include-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of route-object-exclude-always
     * of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
```

```
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-exclude-always/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
    description "OTN label.";
    case otn {
      uses l1-types:otn-label-hop;
    }
  }

  /* Augment label hop of route-object-include-exclude of
   * secondary path */
  augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:explicit-route-objects-always/"
          + "te:route-object-include-exclude/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
    description "OTN label.";
    case otn {
      uses l1-types:otn-label-hop;
    }
  }

  /* Augment label restrictions for the forwarding direction
   * of path-in-segment of secondary path */
  augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction" {

    description "OTN label.";
    uses l1-types:otn-label-range-info;
  }

  /* Augment label restrictions start for the forwarding direction
   * of path-in-segment of secondary path */
  augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
    description "OTN label.";
    case otn {
      uses l1-types:otn-label-start-end;
    }
  }

  /* Augment label restrictions end for the forwarding direction
```

```
     * of path-in-segment of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-in-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions for the forwarding direction
     * of path-out-segment of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction" {
      description "OTN label.";
      uses l1-types:otn-label-range-info;
    }

    /* Augment label restrictions start for the forwarding direction
     * of path-out-segment of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-start/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }

    /* Augment label restrictions end for the forwarding direction
     * of path-out-segment of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:path-out-segment/te:label-restrictions/"
          + "te:label-restriction/te:label-end/"
          + "te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-start-end;
      }
    }
```

```
    /* Augment label hop of path-route of secondary path */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:computed-paths-properties/"
          + "te:computed-path-properties/"
          + "te:path-properties/te:path-route-objects/"
          + "te:path-computed-route-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of record-route of secondary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:lsps/te:lsp/te:lsp-record-route-information/"
          + "te:lsp-record-route-information/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {

      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of path-route of secondary LSP */
    augment "/te:te/te:tunnels/te:tunnel/"
          + "te:p2p-secondary-paths/te:p2p-secondary-path/"
          + "te:lsps/te:lsp/te:path-properties/"
          + "te:path-route-objects/"
          + "te:path-computed-route-object/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
      }
    }

    /* Augment label hop of record-route of LSP */
    augment "/te:te/te:lsps-state/"
          + "te:lsp/te:lsp-record-route-information/"
          + "te:lsp-record-route-information/te:type/te:label/"
          + "te:label-hop/te:te-label/te:technology" {
      description "OTN label.";
      case otn {
        uses l1-types:otn-label-hop;
```

```
      }
    }
  }

  <CODE ENDS>
```

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. These are the subtrees and data nodes and their sensitivity/vulnerability:

/te:te/te:tunnels/te:tunnel /te:te/../te:te-bandwidth/te:technology /te:te/../te:type/te:label/te:label-hop/te:te-label/te:technology /te:te/../te:label-restrictions/te:label-restriction/te:label-start/ te:te-label/te:technology /te:te/../te:label-restrictions/te:label-restriction/te:label-end/te:te-label/te:technology /te:te/../te:label-restrictions/te:label-restriction/ Editors note: we are using simplified description by folding similar branches to avoid repetation.

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:te/../te:type/te:label/te:label-hop/te:te-label/te:technology
Editors note: we are using simplified description by folding similar branches to avoid repetation.

7. IANA Considerations

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

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

This document registers following YANG modules in the YANG Module Names registry [RFC7950].

```
name:         ietf-otn-tunnel
namespace:    urn:ietf:params:xml:ns:yang:ietf-otn-tunnel
prefix:       otn-tunnel
reference:    RFC XXXX
```

8. Acknowledgements

TBD.

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Internet-Draft Ericsson
Intended status: Informational J. Drake, Ed.
Expires: 14 January 2021 Juniper Networks
13 July 2020

Framework for Transport Network Slices
draft-nsdt-teas-ns-framework-04

Abstract

This memo discusses setting up special-purpose transport connections using existing IETF technologies. These connections are called transport slices for the purposes of this memo. The memo discusses the general framework for this setup, the necessary system components and interfaces, and how abstract requests can be mapped to more specific technologies. The memo also discusses related considerations with monitoring and security.

This memo is intended for discussing interfaces and technologies. It is not intended to be a new set of concrete interfaces or technologies. Rather, it should be seen as an explanation of how some existing, concrete IETF VPN and traffic-engineering technologies can be used to create transport slices. Note that there are a number of these technologies, and new technologies or capabilities keep being added. This memo is also not intended presume any particular technology choice.

Status of This Memo

Table of Contents

1. Introduction

This draft provides a framework for discussing transport slices, as defined in [I-D.nsdt-teas-transport-slice-definition] It is the intention in this document to use terminology consistent with this and other definitions provided in that draft.

In particular, this document uses the following terminology defined in the definitions document:

* Transport Slice

* Transport Slice Controller (TSC)

* Transport Network Controller (TNC)

* Northbound Interface (NBI)

* Southbound Interface (SBI)

This framework is intended as a structure for discussing interfaces and technologies. It is not intended to be a new set of concrete interfaces or technologies. Rather, the idea is that existing or under-development IETF technologies (plural) can be used to realize the ideas expressed here.

For example, virtual private networks (VPNs) have served the industry well as a means of providing different groups of users with logically isolated access to a common network. The common or base network that is used to provide the VPNs is often referred to as an underlay network, and the VPN is often called an overlay network. As an example technology, a VPN may in turn serve as an underlay network for transport slices.

Note: It is conceivable that extensions to these IETF technologies are needed in order to fully support all the ideas that can be implemented with slices, but at least in the beginning there is no plan for the creation of new protocols or interfaces.

Driven largely by needs surfacing from 5G, the concept of network slicing has gained traction ([NGMN-NS-Concept], [TS23501], [TS28530], and [BBF-SD406]). In [TS23501], Network Slice is defined as "a logical network that provides specific network capabilities and network characteristics", and a Network Slice Instance is defined as "A set of Network Function instances and the required resources (e.g. compute, storage and networking resources) which form a deployed Network Slice". According to [TS28530], an end-to-end network slice consists of three major types of network segments: Radio Access Network (RAN), Transport Network (TN) and Core Network (CN). Transport network provides the required connectivity between different entities in RAN and CN segments of an end-to-end network slice, with a specific performance commitment. For each end-to-end network slice, the topology and performance requirement on transport network can be very different, which requires the transport network to have the capability of supporting multiple different transport slices.

While network slices are commonly discussed in the context of 5G, it is important to note that transport slices are a narrower concept, and focus primarily on particular network connectivity aspects. Other systems, including 5G deployments, may use transport slices as a component to create entire systems and concatenated constructs that match their needs, including end-to-end connectivity.

A transport slice could span multiple technologies and multiple administrative domains. Depending on the transport slice consumer's requirements, a transport slice could be isolated from other, often concurrent transport slices in terms of data, control and management planes.

The consumer expresses requirements for a particular transport slice by specifying what is required rather than how the requirement is to be fulfilled. That is, the transport slice consumer's view of a transport slice is an abstract one.

Thus, there is a need to create logical network structures with required characteristics. The consumer of such a logical network can require a degree of isolation and performance that previously might not have been satisfied by traditional overlay VPNs. Additionally, the transport slice consumer might ask for some level of control of their virtual networks, e.g., to customize the service paths in a network slice.

This document specifies a framework for the use of existing technologies as components to provide a transport slice service, and might also discuss (or reference) modified and potential new technologies, as they develop (such as candidate technologies described in section 5 of [I-D.ietf-teas-enhanced-vpn]).

2. Transport Slice Objectives

It is intended that transport slices can be created to meet specific requirements, typically expressed as bandwidth, latency, latency variation, and other desired or required characteristics. Creation is initiated by a management system or other application used to specify network-related conditions for particular traffic flows.

And it is intended that, once created, these slices can be monitored, modified, deleted, and otherwise managed.

It is also intended that applications and components will be able to use these transport slices to move packets between the specified end-points in accordance with specified characteristics.

As an example of requirements that might apply to transport slices, see [I-D.ietf-teas-enhanced-vpn] (in particular, section 3).

3. Framework

A number of transport slice services will typically be provided over a shared underlying network infrastructure. Each transport slice consists of both the overlay connectivity and a specific set of dedicated network resources and/or functions allocated in a shared underlay network to satisfy the needs of the transport slice consumer. In at least some examples of underlying network technologies, the integration between the overlay and various underlay resources is needed to ensure the guaranteed performance requested for different transport slices.

Transport Slice Definition ([I-D.nsdt-teas-transport-slice-definition]) defines the role of a Customer (or User) and a Transport Slice Controller. That draft also defines a TSC Northbound Interface (NBI).

A transport slice user is served by the Transport Slice Controller (TSC), as follows:

* The TSC takes requests from a management system or other application, which are then communicated via an NBI. This interface carries data objects the transport slice user provides, describing the needed transport slices in terms of topology, applicable service level objectives (SLO), and any monitoring and reporting requirements that may apply. Note that - in this context - "topology" means what the transport slice connectivity is meant to look like from the user's perspective; it may be as simple as a list of mutually (and symmetrically) connected end points, or it may be complicated by details of connection asymmetry, per-connection SLO requirements, etc.

* These requests are assumed to be translated by one or more underlying systems, which are used to establish specific transport slice instances on top of an underlying network infrastructure.

* The TSC maintains a record of the mapping from user requests to slice instantiations, as needed to allow for subsequent control functions (such as modification or deletion of the requested slices), and as needed for any requested monitoring and reporting functions.

Section 3 of [I-D.ietf-teas-enhanced-vpn] provides an example architecture that might apply in using the technology described in that document.

3.1. Management systems or other applications

The transport slice system is used by a management system or other application. These systems and applications may also be a part of a higher level function in the system, e.g., putting together network functions, access equipment, application specific components, as well as the transport slices.

3.2. Expressing connectivity intents

The Transport Slice Controller (TSC) northbound interface (NBI) can be used to communicate between transport slice users (or consumers) and the TSC.

A transport slice user may be a network operator who, in turn, provides the transport slice to another transport slice user or consumer.

Using the NBI, a consumer expresses requirements for a particular slice by specifying what is required rather than how that is to be achieved. That is, the consumer's view of a slice is an abstract one. Consumers normally have limited (or no) visibility into the provider network's actual topology and resource availability information.

This should be true even if both the consumer and provider are associated with a single administrative domain, in order to reduce the potential for adverse interactions between transport slice consumers and other users of the transport network infrastructure.

The benefits of this model can include:

* Security: because the transport network (or network operator) does not need to expose network details (topology, capacity, etc.) to transport slice consumers the transport network components are less exposed to attack;

* Layered Implementation: the transport network comprises network elements that belong to a different layer network than consumer applications, and network information (advertisements, protocols, etc.) that a consumer cannot interpret or respond to (note - a consumer should not use network information not exposed via the TSC NBI, even if that information is available);

* Scalability: consumers do not need to know any information beyond that which is exposed via the NBI.

The general issues of abstraction in a TE network is described more fully in [RFC7926].

This framework document does not assume any particular layer at which transport slices operate as a number of layers (including virtual L2, Ethernet or IP connectivity) could be employed.

Data models and interfaces are of course needed to set up transport slices, and specific interfaces may have capabilities that allow creation of specific layers.

Layered virtual connections are comprehensively discussed in IETF documents and are widely supported. See, for instance, GMPLS-based networks ([RFC5212] and [RFC4397]), or ACTN ([RFC8453] and [RFC8454]). The principles and mechanisms associated with layered networking are applicable to transport slices.

There are several IETF-defined mechanisms for expressing the need for a desired logical network. The NBI carries data either in a protocol-defined format, or in a formalism associated with a modeling language.

For instance:

* Path Computation Element (PCE) Communication Protocol (PCEP) [RFC5440] and GMPLS User-Network Interface (UNI) using RSVP-TE [RFC4208] use a TLV-based binary encoding to transmit data.

* Network Configuration Protocol (NETCONF) [RFC6241] and RESTCONF Protocol [RFC8040] use XML abnd JSON encoding.

* gRPC/GNMI [I-D.openconfig-rtgwg-gnmi-spec] uses a binary encoded programmable interface;

* SNMP ([RFC3417], [RFC3412] and [RFC3414] uses binary encoding (ASN.1).

* For data modeling, YANG ([RFC6020] and [RFC7950]) may be used to model configuration and other data for NETCONF, RESTCONF, and GNMI - among others; ProtoBufs can be used to model gRPC and GNMI data; Structure of Management Information (SMI) [RFC2578] may be used to define Management Information Base (MIB) modules for SNMP, using an adapted subset of OSI's Abstract Syntax Notation One (ASN.1, 1988).

While several generic formats and data models for specific purposes exist, it is expected that transport slice management may require enhancement or augmentation of existing data models.

3.3. Transport Slice Controller (TSC)

The transport slice controller takes abstract requests for transport slices and implements them using a suitable underlying technology. A transport slice controller is the key building block for control and management of the transport slice. It provides the creation/modification/deletion, monitoring and optimization of transport Slices in a multi-domain, a multi-technology and multi-vendor environment.

A TSC northbound interface (NBI) is needed for communicating details of a transport slice (configuration, selected policies, operational state, etc.), as well as providing information to a slice requester/consumer about transport slice status and performance. The details for this NBI are not in scope for this document.

The controller provides the following functions:

* Provides a technology-agnostic NBI for creation/modification/deletion of the transport slices. The API exposed by this NBI communicates the endpoints of the transport slice, transport slice SLO parameters (and possibly monitoring thresholds), applicable input selection (filtering) and various policies, and provides a way to monitor the slice.

* Determines an abstract topology connecting the endpoints of the transport slice that meets criteria specified via the NBI.The TSC also retains information about the mapping of this abstract topology to underlying components of the transport slice as necessary to monitor transport slice status and performance.

* Provides "Mapping Functions" for the realization of transport slices. In other words, it will use the mapping functions that:

  map technology-agnostic NBI request to technology-specific SBIs.

  map filtering/selection information as necessary to entities in the underlay network.

* Via an SBI, the controller collects telemetry data (e.g. OAM results, statistics, states etc.) for all elements in the abstract topology used to realize the transport slice.

* Using the telemetry data from the underlying realization of a transport slice (i.e. services/paths/tunnels), evaluates the current performance against transport slice SLO parameters and exposes them to the transport slice consumer via the NBI. The TSC NBI may also include a capability to provide notification in case

the transport slice performance reaches threshold values defined by the transport slice consumer.

3.3.1. Northbound Interface (NBI)

The Transport Slice Controller provides a Northbound Interface (NBI) that allows consumers of network slices to request and monitor transport slices. Consumers operate on abstract transport slices, with details related to their realization hidden.

The NBI complements various IETF services, tunnels, path models by providing an abstract layer on top of these models.

The NBI is independent of type of network functions or services that need to be connected, i.e. it is independent of any specific storage, software, protocol, or platform used to realize physical or virtual network connectivity or functions in support of transport slices.

The NBI uses protocol mechanisms and information passed over those mechanisms to convey desired attributes for transport slices and their status. The information is expected to be represented as a well-defined data model, and should include at least endpoint and connectivity information, SLO specification, and status information.

To accomplish this, the NBI needs to convey information needed to support communication across the NBI, in terms of identifying the transport slices, as well providing the above model information.

3.4. Mapping

The main task of the transport slice controller is to map abstract transport slice requirements to concrete technologies and establish the required connectivity, and ensuring that required resources are allocated to the transport slice.

3.5. Underlying technology

There are a number of different technologies that can be used, including physical connections, MPLS, TSN, Flex-E, etc.

See [I-D.ietf-teas-enhanced-vpn] - section 5 - for instance, for example underlying technologies.

Also, as outlined in "applicability of ACTN to Transport Slices" below, ACTN ([RFC8453]) offers a framework that is used elsewhere in IETF specifications to create virtual network (VN) services similar to Transport Slices.

A transport slice can be realized in a network, using specific underlying technology or technologies. The creation of a new transport slice will be initiated with following three steps:

* Step 1: A higher level system requests connections with specific characteristics via NBI.

* Step 2: This request will be processed by a Transport Slice Controller which specifies a mapping between northbound request to any IETF Services, Tunnels, and paths models.

* Step 3: A series of requests for creation of services, tunnels and paths will be sent to the network to realize the trasport slice.

It is very clear that regardless of how transport slice is realized in the network (i.e. using tunnels of type RSVP or SR), the definition of transport slice does not change at all but rather its realization.

4. Applicability of ACTN to Transport Slices

Abstraction and Control of TE Networks (ACTN - [RFC8453]) is an example of similar IETF work. ACTN defines three controllers to support virtual network (VN) services -

* Customer Network Controller (CNC),

* Multi-Domain Service Coordinator (MDSC) and

* Provisioning Network Controller (PNC).

A CNC is responsible for communicating a customer's VN requirements.

A MDSC is responsible for multi-domain coordination, virtualization (or abstraction), customer mapping/translation and virtual service coordination to realize the VN requirement. Its key role is to detach the network/service requirements from the underlying technology.

A PNC oversees the configuration, monitoring and collection of the network topology. The PNC is a underlay technology specific controller.

While the ACTN framework is a generic VN framework that is used for various VN service beyond the transport slice, it is still a suitable basis to understand how the various controllers interact to realize a transport slice.

One possible mapping between the transport slice, and ACTN, definitions is as shown in Figure 1 below.

```
+---------------------------------------+
|               Customer                |  |
+---------------------------------------+
                  ^                        |      ACTN
                  |                        |   Terminology
                  v                        |   and Concepts
+---------------------------------------+
| A higher level operation system       |  |    +-----+
|(e.g. e2e network slice orchestrator)| ===> | CNC |
+---------------------------------------+  |    +-----+
                  ^                                 ^
                  | TSC NBI                |        | CMI
                  v                                 v
+---------------------------------------+  |    +------+
|      Transport Slice Controller       | ===> | MDSC |
+---------------------------------------+  |    +------+
                  ^                                 ^
                  | TSC SBI                |        | MPI
                  v                                 v
+---------------------------------------+  |    +-----+
|   Transport Network Controller(s)     | ===> | PNC |
+---------------------------------------+  |    +-----+

         Terminology/Concepts              |
        Used in this Document
                                           |
```

Figure 1

Note that the left-hand side of this figure comes from Transport Slice Definition ([I-D.nsdt-teas-transport-slice-definition]).

The TSC NBI conveys the generic transport slice requirements. These may then be realized using an SBI within the TSC.

As per [RFC8453] and [I-D.ietf-teas-actn-yang], the CNC-MDSC Interface (CMI) is used to convey the virtual network service requirements along with the service models and the MDSC-PNC Interface (MPI) is used to realize the service along network configuration models. [I-D.ietf-teas-te-service-mapping-yang] further describe how the VPN services can be mapped to the underlying TE resources.

The Transport Network Controller (TNC) is depicted as a single block, analogous to the Provisioning Network Controller (in this example). In the ACTN framework, however, it is also possible that the TNC function is decomposed into MDSC and PNC - that is, the TNC may comprise hierarchy as needed to handle the multiple domains and various underlay technologies, whereas a PNC in ACTN is intended to be specific to at most a single underlay technology and (likely) to individual devices (or functional components).

Note that the details of potential implementations of everything that is below the TSC in Figure 1 are out of scope in this document - hence the specifics of the relationship between TNC and PNC, and the possibility that the MDSC and PNC may be combined are at most academically interesting in this context. Another way to view this is that, in the same way that ACTN might combine MDSC and PNC, the TSC might also directly include TNC functionality.

[RFC8453] also describes TE Network Slicing in the context of ACTN as a collection of resources that is used to establish a logically dedicated virtual network over one or more TE networks. In case of TE enabled underlying network, ACTN VN can be used as a base to realize the transport network slicing by coordination among multiple peer domains as well as underlay technology domains.

Figure 1 shows only one possible mapping as each ACTN component (or interface) in the figure may be a composed differently in other mappings, and the exact role of both components and subcomponents will not be always an exact analogy between the concepts used in this document and those defined in ACTN.

This is - in part - shown in a previous paragraph in this section where it is pointed out that the TNC may actually subsume some aspects of both the MDSC and PNC.

Similarly, in part depending on how "customer" is interpreted, CNC might merge some aspects of the higher level system and the TSC. As in the TNC/PNC case, this way of comparing ACTN to this work is not useful as the TSC and TSC NBI are the focus on this document.

5. Considerations

5.1. Monitoring

Transport slice realization needs to be instrumented in order to track how it is working, and it might be necessary to modify the transport slice as requirements change. Dynamic reconfiguration might be needed.

5.2. Security Considerations

Transport slices might use underlying virtualized networking. All types of virtual networking require special consideration to be given to the separation of traffic between distinct virtual networks, as well as some degree of protection from effects of traffic use of underlying network (and other) resources from other virtual networks sharing those resources.

For example, if a service requires a specific upper bound of latency, then that service can be degraded by added delay in transmission of service packets through the activities of another service or application using the same resources.

Similarly, in a network with virtual functions, noticeably impeding access to a function used by another transport slice (for instance, compute resources) can be just as service degrading as delaying physical transmission of associated packet in the network.

While a transport slice might include encryption and other security features as part of the service, consumers might be well advised to take responsibility for their own security needs, possibly by encrypting traffic before hand-off to a service provider.

5.3. Privacy Considerations

Privacy of transport network slice service consumers must be preserved. It should not be possible for one transport slice consumer to discover the presence of other consumers, nor should sites that are members of one transport slice be visible outside the context of that transport slice.

In this sense, it is of paramount importance that the system use the privacy protection mechanism defined for the specific underlying technologies used, including in particular those mechanisms designed to preclude acquiring identifying information associated with any transport slice consumer.

5.4. IANA Considerations

There are no requests to IANA in this framework document.

6. Acknowledgments

The entire TEAS NS design team and everyone participating in related discussions has contributed to this draft. Some text fragments in the draft have been copied from the [I-D.ietf-teas-enhanced-vpn], for which we are grateful.

Significant contributions to this document were gratefully received from the contributing authors listed in the "Contributors" section. In addition we would like to also thank those others who have attended one or more of the design team meetings, including:

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* Shunsuke Homma

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September 9, 2020

IETF Definition of Transport Slice
draft-nsdt-teas-transport-slice-definition-04

Abstract

This document describes the definition of a slice in the transport networks and its characteristics. The purpose here is to bring clarity and a common understanding of the transport slice concept and describe related terms and their meaning. It explains how transport slices can be used in combination with end to end network slices, or independently.

Status of This Memo

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Table of Contents

1. Introduction

A number of use cases benefit from establishing network connectivity providing transport and assurance of a specific set of network resources. In this document, as detailed in the subsequent sections, we refer to this connectivity and resource commitment as the transport slice. Services that might benefit from the transport slices include but not limited to:

o 5G services (e.g. eMBB, URLLC, mMTC)(See [TS.23.501-3GPP])

- o Network wholesale services
- o Network infrastructure sharing among operators
- o NFV connectivity and Data Center Interconnect

This document defines the concept of transport slices that provide connectivity with a specific commitment of network resources between a number of end points over a shared network infrastructure.

1.1. Rationale

Transport slices are created and managed within the scope of one or more underlying network technologies (e.g., IP, MPLS, optical). Transport slices are expected to enable a diverse set of applications that have different requirements to coexist on the same network infrastructure.

Transport slice is described as a construct that specifies connectivity requirements, emphasizing on assurance of those requirements. Transport slice is unaware of the underlying infrastructure connectivity (hence, the term "transport"). The types of underlying networking technologies can be based on any combination of IP, Ethernet, MPLS, and optical technologies. Transport slices also include specification of resources related to network functions required by customer applications.

Traditionally, VPNs have focussed on segmentation, i.e., creation and management of the private networks. They are bound to a specific traffic type and are technology specific. In contrast, transport slices concern with the assurance of resources required from the network and provide a common user interface for describing those resources. A service provider can use many aspects of the VPNs to build the transport slices.

Transport slices relate to a more general topic of network slicing. It is not the goal of this document to define this broader concept, but in general, it is to identify the methodology to describe the logical (or abstract) partitioning of network resources associated with a service or an application.

2. Terms and Abbreviations

The terms and abbreviations used in this document are listed below.

- o E2E NS: End to End Network Slice
- o TS: Transport Slice

- TSC: Transport Slice Controller
- EP: Endpoint
- EU: End User
- NBI: NorthBound Interface
- SBI: SouthBound Interface
- SLI: Service Level Indicator A well defined quantitative measure of some aspect of the level of service that is provided.
- SLO: Service Level Objective A target value or range of values for a service level that is measured by an SLI. A natural structure for SLOs is thus SLI <= target, or lower bound <= SLI <= upper bound.
- SLA: Service Level Agreement An explicit or implicit contract with the end users that includes consequences of meeting (or missing) the SLOs they contain.

The above terminology is described in greater detail in the remainder of this document.

3. Definition and Scope of Transport Slice

The definition of a transport slice is as follows:

"A transport slice is a logical network topology connecting a number of endpoints with a set of shared or dedicated network resources, that are used to satisfy specific Service Level Objectives (SLOs)".

The text below describes transport slices in more details.

Transport slice specification is technology-agnostic, and the means for transport slice realization can be chosen depending on several factors such as: service requirements, specifications or capabilities of underlying infrastructure. The structure and different characteristics of transport slices are described in the following sections.

The term "transport" in transport slice is derived from the definition of Transport Network in the section 1.3.1 of [RFC5921] : A Transport Network provides transparent transmission of user traffic between attached client devices by establishing and maintaining point-to-point or point-to-multipoint connections between such devices. "Slice" refers to a set of characteristics that separate one type of user-traffic from other types. Transport slice assumes that an underlying transport network is capable of changing the configurations of the network devices on demand, through in-band signaling or via controller(s) and to provide transport transmissions with fulfilling all or some of SLOs to all of the traffic in the slice or to specific flows.

4. Transport Slice System Characteristics

The following subsections describe the characteristics needed for support of transport slices.

4.1. Service Level Objectives for Transport Slices

A transport slice is defined in terms of several quantifiable characteristics or service level objectives (SLOs). These objectives define a set of network resource parameters or values necessary to provide a service as requested for a given transport slice. SLOs do not describe 'how' the transport slices will be implemented or realized in the underlying network layers. Instead, they are defined in terms of dimensions of operations (time, capacity, etc.), availability and other attributes. A transport slice can have one or more SLOs associated with it, all SLO's combined to form an SLA. The SLO values are defined unidirectionally and for specific subsets of two or more endpoints (i.e. for a subset of connections in transport slice).

The SLOs and values associated with them that are exposed to the end user, are in the form of Service Level Indicators (SLIs). If for example the range of latencies a network can provide is 50ms-100ms, then this would be the range of values the end user should be able to request, it would be as low as 50ms or as high as 100ms or anything in between. The values of requested SLOs should always be in the range of values supported. The underlying networks must provide means to monitor and measure the performance of transport slices against the SLOs requested and verify that they are being met. Some SLOs can be measured directly through a collection of metrics and statistics from the network (commonly known as 'telemetry'), while others are deduced from measurable objectives and may require additional tools or mechanisms to measure their target values.

4.1.1. Minimal Set of SLOs

This document defines a minimal set of SLOs and later systems or standards could extend this set and define more SLOs. For example, we included Guaranteed bandwidth which is the minimum requested bandwidth for the transport slice. The later standard might define other SLOs related to bandwidth if needed.

Accordingly, SLOs can be categorized in to 'Directly Measurable Objectives' or 'Indirectly Measurable Objectives' as follows:

Some of the 'Directly Measurable Objectives' are:

- o Guaranteed Minimum Bandwidth
- o Guaranteed Maximum Latency
- o Maximum permissible delay variation
- o Maximum permissible packet loss rate
- o Availability
- o Other objectives could be specified

Some of the 'Indirectly Measurable Objectives' are:

- o Security
- o others objectives such as geographical restrictions, maximum occupancy level, etc. could be specified

The definition of these objectives are as follows:

- o Guaranteed Minimum Bandwidth: Minimum guaranteed bandwidth between two endpoints at any time. The bandwidth is measured in data rate units of bits per second and is measured unidirectionally.

- o Guaranteed Maximum Latency: Upper bound of network latency when transmitting between two endpoints. The latency is measured in terms of network characteristics (excluding application-level latency). [RFC2681] and [RFC7679] discuss round trip times and one-way metrics, respectively.

- o Maximum permissible delay variation: Packet delay variation (PDV) as defined by [RFC3393], is measured by the difference in the one-way delay between sequential packets in a flow. Minimizing variations in the delay is important for real-time applications.

- o Maximum permissible packet loss rate: is defined by the ratio of packets dropped to packets transmitted between two endpoints. See [RFC7680]

- o Availability: is defined as the ratio of uptime to total_time(uptime+downtime), where uptime is the time the transport slice is available in accordance with the SLOs associated with it.

- Security: This objective may request for encryption [RFC4303] between two end-points explicitly to meet architecture recommendations as in [TS33.210] or for compliance with [HIPAA] [PCI]. Other security requests may be made as specified in [draft-ietf-i2nsf-capability].

  * Note: Security violations are not directly observable and cannot be measured as quantifiable metrics. Still, the user of the transport slice should be able to request certain criteria for compliance and identify exceptions and unexpected traffic. For this purpose [i2nsf-nsf-monitoring-data-model] can be leveraged.

4.1.2. Other Objectives

Additional objectives, such as certain geographical restrictions or well defined domains that a slice may transit may be necessary.

Optionally, when the customer is traffic aware, other traffic specific characteristics may be provided. These include for example, MTU, traffic-type (e.g., IPv4, IPv6, Ethernet or unstructured), or a higher-level behavior to process traffic according to user-application (which may be realized using network functions).

Maximal occupancy for a transport slice should be provided. Since it carries traffic for multiple flows between the two endpoints, the objectives should also say if they are for the entire connection, group of flows or on per flow basis. Maximal occupancy should specify the scale of the flows (i.e. maximum number of accommodatable flows) and optionally a maximum number of countable resource units, e.g IP or MAC addresses a slice might consume.

With these objectives incorporated, a customer sees transport slice as a dedicated network for its exclusive use. Achieving this may require explicit request for different types of isolation in provider networks as described in Section 6.

Additional description of slice attributes is covered in a broader context of 'Generic Network Slice Template' in [I-D.contreras-teas-slice-nbi].

4.2. Transport Slice Endpoints

The transport slice endpoints are the conceptual entities that perform any required conversion, or adaptation, and forwarding of the user traffic. The characteristics of the transport slice endpoints (TSE) are:

- They are conceptual points of connection of a network function, device or application to the transport slice

- They are identified in a request provided by the customer of transport slice (i.e. higher level operation systems) during the creation of the transport slice

- They are associated with a device, application and/or network function nodes. A non-exhaustive list of such nodes are routers, switches, firewalls, WAN, 4G/5G RAN nodes, 4G/5G Core nodes, application acceleration, Deep Packet Inspection (DPI), server load balancers, NAT44 [RFC3022], NAT64 [RFC6146], HTTP header enrichment functions, and TCP optimizers

- A TSE is identified by its associated node (its IP address, name , ID, etc.), a unique identifier and/or a unique name and other data. A non-exhaustive list of other data includes IP address (v4 or v6), VLAN, port, connectivity type (P2P, P2MP, MP2MP). TBD for more

Note that the TSE is different from access points (AP) defined in [RFC8453] as an AP is a logical identifier to identify the shared link between the customer and the operator where as TSE is an identifier of an endpoint. Also TSE is different from TE Link Termination Point (LTP) defined in [I-D.ietf-teas-yang-te-topo] as it is a conceptual point of connection of a TE node to one of the TE links on a TE node.

The TSE is similar to the Termination Point (TP) defined in [RFC8345] and can contain more attributes. TSE could be modeled by augmenting the TP model.

There is another type of the endpoints called "Transport Slice Realization endpoints (TSREs)". These endpoints are allocated and assigned by the network controller during the realization of a transport slice and are technology-specific, i.e. they depend on the network technology used during the transport slice realization. They are identified by a node and some associated data. A non-exhaustive list of nodes containing TSREs are routers, switches, PON nodes, Wireless nodes and Optical devices.

Note that there will be a mapping between TSE and TSRE on Transport Slice Controller (TSC). When TSC receives a request via its NBI to create a transport slice between multiple TSEs, it will send the request via its SBI to realize the transport slice. The TSRE will be notified by network controller during TS realization to enable mapping between TSREs and the TSEs.

Figure 1 shows an example of a transport slice and its realization between multiple TSEs and TSREs.

```
                           (-------------------)
                          (  Transport Network  )
        DAN1             (                        )              DAN2
     --------  TSRE1 --------                  -------- TSRE2   --------
     |    o |-------o|  A   |                  |  B   |o--------| o    |
     |  TSE1|        --------                  --------         | TSE2 |
     --------         |   (                        )  |         --------
          |           |    (                      )   |            |
          |           |     (-------------------)     |            |
          |           |                               |            |
          |           | <=============================> |          |
          |               Transport slice realization              |
          |                 between TSRE1 and TSRE2                |
          |                                                        |
          | <===================================================>  |
                Transport slice between TSE1 and TSE2 with SLO1
```

Legend:
   DAN: Device, application and/or network function

Figure 1: A transport slice between TSEs and its realization between TSREs

4.2.1. Transport Slice Connectivity Types

The transport slices connection types can be point to point (P2P), point to multipoint (P2MP), multi-point to point (MP2P), or multi-point to multi-point (MP2MP). The transport slice connection type will requested by the higher level operation system.

4.3. Vertical Composition of Transport Slice

Transport slice may follow a hierarchical relationship to provide a vertical structure to it. This is used for composing multi-layer slices in which each layer provides an abstraction, as well as an independent monitoring, performance, control and management of the resources. The vertical transport slice characteristic could be used in 2 forms:

- o The Transport slice itself where it represents a hierarchy of abstracted transport slices. In this case, the realization will be done just once with a particular technology. Thus, the lowest transport slice in the hierarchy that can not be decomposed further will be one to one mapping to its instance of the realized transport slice.

- o Each layer (physical, datalink, or IP) has its own set of resources that can be provided to the upper layer as a transport slice. Thus, transport slice at one layer is used by the layer above. This type of multi-layer vertical transport slice associates resources at different layers. For example, an IP transport slice would utilize one or more optical transport slice. In this case, the realization will be done for a particular technology at that particular layer. Thus, the lowest transport slice in this type of hierarchy that can not be decomposed further will be an instance of realized physical layer transport slice.

```
         <======================== TS1 ========================>
         <=====TS11=======>  <=============TS12===============>
                             <====TS121====>  <=====TS122======>
             .--.              .--.                .--.
            (    )--.         (    )--.           (    )--.
           .'        '       .'        '         .'        '
 [EU-x]   (  Network-1  )  (  Network-2  ) ... (  Network-3 )  [EU-y]
            `-----------'    `-----------'      `----------'
         |                |                                    |
         |   Operator-y   |           Operator-z               |

    Legend:
      TSnnn: Level 3 vertical transport slice nnn
      TSnn:  Level 2 vertical transport slice nn
      TSn:   Level 1 transport Slice n
```

Figure 2: Transport Slice Vertical and Horizontal Composition

Figure 2 shows the transport slice hierarchy. Slices TS11 and TS12 are composed together to form TS1 that is the top level transport slice definition, TS121 and TS122 collectively define TS12. The SLO for bandwidth guarantee will be shared and latency guarantee will be split into latency in networks 2 and 3. To emphasize the hierarchical structure, consider Network-2 and Network-3 are in the same administrative domain but use different transport technologies respectively. Then instead of presenting 2 transport slices, Operator-z can expose only one transport slice TS12 abstracting the underlying transport technology details.

Note: The specification to connect TS121 and TS122 are similar to those connecting TS12 and TS11.

4.4. Horizontal Composition of Transport Slice

In contrast, horizontal transport slices enable the composition of multiple realized transport slices. Since transport slices are not necessarily a single encapsulation tunnel and may traverse through different data planes, each realized transport slice will require a stitching, interworking or mapping function. These stitching functions can be viewed as a type of intermediate network function endpoints. For instance in Figure 2, TS11 and TS12 are horizontal transport slices. If we assume that TS11 is an L2 tunnel and TS12 is an SRV6 based path, then a 'Service type EP' (not shown in the figure) is needed for translation.

Author's notes: This service type EP is a new type of transport slice specific service function. We may call it transport slice gateway.

5. Transport Slice Structure

A transport slice is a set of connections among various endpoints to form a logical network that meets the SLOs agreed upon.

```
             ____________________________
[EP11]------/                            /--[EP21]
           /                            /
[EP12]----/     Transport Slice       /----[EP22]
  :      /        (SLOs e.g.        /
  :     / B/W > x bps, Delay < y ms)/
[EP1m]-/___________________________/-------[EP2n]

== == == == == == == == == == == == == == == == == ==

           .--.                  .--.
[EP11]    (    )- .             (    )- .     [EP21]
         .'         '  SLO  .'         '
[EP12]  (  Network-1 ) ... (  Network-p )  [EP22]
 :       `-----------'      `-----------'     :
[EP1m]                                     [EP2n]

Legend
  SLOs in terms of attributes, e.g. BW, delay.
  EP: Endpoint
  B/W: Bandwidth
```

Figure 3: Transport slice

Figure 3 illustrates a case where a transport slice provides connectivity between a set of endpoints pairs with specific characteristics for each SLO (e.g. guaranteed minimum bandwidth of x bps and guaranteed delay of less than y ms). The endpoints may be distributed in the underlay networks, and a transport slice can be deployed across multiple network domains. Also, the endpoints on the same transport slice may belong to the same address space.

Transport slices involve both customer's and provider's views. A customer 'describes' its requirements in terms of connectivity with specific SLOs. Provider networks address those requirements through 'transport slice realization' (its implementation) using provider network specific technologies.

A transport slice is requested from an entity (such as an orchestrator or a system-wide controller) performing broader service or application specific functions. The interface from such an entity should express the needed connectivity in a technology-agnostic way and donot need to recognize configurations based on the technologies (e.g. being more declarative than imperative). The request to instantiate a transport slice is only represented with some indicators such as SLOs based on which the underlying technologies are selected and managed.

Often, in other SDOs the term sub-slice or slice-subnet comes up. Some of those are mapped to transport network requirements in the form of a transport slice. With in the scope of transport slices (w.r.t. the IP/MPLS based transport networks) there are no definitions for 'sub-slice' or 'slice subnets'. 'Transport slice' term universally represents SLO and connectivity requirements from the transport networks.

Furthermore, the structure of transport slices may be layered vertically or composed horizontally, i.e. operationally, a transport slice maybe decomposed in two or more transport slices which are then independently realized and managed. This is further described in Section 4.3.

5.1. Stakeholders

A transport slice and its realization involves the following stakeholders and it is relevant to define them for consistent terminology.

Customer or User: A customer is a user of a transport slice. Customers may request monitoring of associated resources or specific changes. A user may either directly manage its service by interfacing with the transport slice controller or indirectly through an orchestrator.

Orchestrator: An orchestrator is an entity that composes different services, resource and network requirements. It interfaces with the transport slice controllers.

Transport Slice Controller (TSC): It realizes a transport slice in the network, maintains and monitors the run-time state of resources and topologies associated with it. A well-defined interface is needed between different types of transport slice controllers and different types of orchestrators. A transport slice operator (or slice operator for short) manages one or more transport slices using the Transport Slice Controller(s).

Transport Network Controller: is a form of network infrastructure controller that offers network resources to TSC to realize a particular transport slice. These may be existing network controllers associated with one or more specific technologies that may be adapted to the function of realizing transport slices in a network.

5.2. Transport Slice Controller Interfaces

The interworking and interoperability among the different stakeholders to provide common means of provisioning, operating and monitoring the transport slices is a mandatory requirement. The following communication interfaces are identified (see Figure 4).

TSC Northbound Interface (NBI): The TSC Northbound Interface is an interface between a higher level operation system, e.g. 'E2E network slice orchestrator' and the 'Transport slice controller'. It is a technology agnostic interface. Over this NBI, slice characteristics and other requirements can be communicated to TSC and the operational state of a transport slice may be requested.

TSC Southbound Interface (SBI): The TSC Southbound Interface is an interface between 'Transport slice controller (TSC)' and network controller(s). These interfaces are technology-specific and utilize many of the network models.

```
+-------------------------------------------+
|                Customer                   |
+-------------------------------------------+
                      A
                      |
                      V
+-------------------------------------------+
|      A higher level operation system      |
|    (e.g e2e network slice orchestrator)   |
+-------------------------------------------+
                      A
                      | TSC NBI
                      V
+-------------------------------------------+
|          Transport Slice Controller       |
+-------------------------------------------+
                      A
                      | TSC SBI
                      V
+-------------------------------------------+
|            Network Controller(s)          |
+-------------------------------------------+
```

Figure 4: Interface of Transport Slice Controller

5.3. Transport slice Realization

Realization of a Transport Slice is a mapping of underlying infrastructure with its definition. It is a technology specific entity that is created and maintained over its southbound interfaces. The Network controller(s) export the connectivity and resource mappings to the TSC. The network controller abstracts the details of underlying resources from the TSC.

The realization can be achieved in the form of either physical or logical connectivity through VPNs, a variety of tunneling technologies such as Segment Routing, SFC, etc. Accordingly, endpoints may be realized as physical or logical service or network functions.

6. Isolation in Transport Slices

6.1. Traffic Isolation

This section will describe the scope and use of term isolation.

6.2. Dedicated Resources

This section explains the scope and use of term dedicated resource in the context of transport slices.

7. Relationship with End-to-End Network Slicing

An end-to-end (E2E) network slice is a complete logical network that provides a service in its entirety with a specific assurance to the customer. A transport slice concerns with those assurance aspects only within the transport networks. Consider Figure 5, where a network operator has an E2E network slice that traverses multiple technology-specific networks. Each of these networks might use any number of technologies, including but not limited to IP, MPLS, Fiber-Optics (e.g. WDM, DWDM), Passive Optical Networking (PON), Microwave, etc.

Each of these networks includes multiple (physical or virtual) nodes and may also provide network functions beyond simply carrying of technology-specific protocol data units. The types of nodes used in any of these networks may include:

- o Packet/frame processing nodes (e.g., Routers, Switches)

- o Application servers

- o Service Functions(e.g., Firewall, Loadbalancer) o Radio Access Network (RAN) components

o Mobile Core components

o Microwave transceivers

o Optical repeaters

o etc.

Each network may support different technologies and an E2E network slice is a combination of these networks. As an example:

o Network 1 might contain multiple 5G RAN nodes connected to a few Cell Site Gateways (CSG) routers.

o Network 2 might have one or more layer-3 routers and layer-2 switches which may run on top of an optical network.

o Network 3 might have a number of 5G RAN nodes connected to Passive Optical Network (PON) switches.

```
           <====================== E2E NS ======================>
           <-OS1-> <-TS1-> <-TS2-> <-OS2->    ...   <-TSn-> <-OSm->
          |------------------------------------------------------|
          |                                                      |
          |    .--.             .--.                 .--.        |
          |   (    )--.        (    )--.            (    )--.    |
          |  .'         '    .'         '         .'         '   |
   [EU-x] |  (  Network-1  )  (  Network-2  ) ... (  Network-p )  |[EU-y]
          |   `-----------'    `-----------'       `----------'  |
          |                                                      |
          |                      Operator-z                      |
          |------------------------------------------------------|
   Legend:
     E2E NS: End-to-end network slice
     TSn: Transport Slice n
     OSm: Other Slice m
     EU-x: End User-x
     EU-y: End User-y
```

Figure 5: E2E network slice

When operator-z creates a specific E2E network slice, it may create one or more of transport slices and other slices (application logic or other system functions).

An independent E2E logical network (called E2E network slice) is created for a service (e.g. CCTV, autonomous driving, HD map, etc.) with a specific network SLOs, e.g. a secure connection with an E2E latency less than 5ms, from End User-x (EU-x) to End User-y (EU-y). EU-x maybe a 5G user equipment such as an infotainment unit in a car, CCTV, or a car for autonomous driving, etc. and EU-y in 5G is 5G application server, IMS, etc.

In Figure 5, "E2E NS" is that logical network with requested SLO between EU-x to EU-y and is associated with a customer and a specific service type.

8. Security Considerations

Not applicable in this memo.

9. IANA Considerations

This memo includes no request to IANA.

10. Acknowledgment

The entire TEAS NS design team and everyone participating in those discussion has contributed to this draft. Particularly, Eric Gray, Xufeng Liu, Jie Dong, and Jari Arkko for a thorough review among other contributions.

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