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A YANG Data Model for VN Operation

Abstract

This document provides a YANG data model generally applicable to any mode of Virtual Network (VN) operation.

Status of This Memo

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This Internet-Draft will expire on 8 September 2022.

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1. Introduction

This document provides a YANG [RFC7950] data model generally applicable to any mode of Virtual Network (VN) operation.

The VN model defined in this document is applicable in generic sense as an independent model in and of itself. The VN model defined in this document can also work together with other customer service models such as L3SM [RFC8299], L2SM [RFC8466] and L1CSM [I-D.ietf-ccamp-l1csm-yang] to provide a complete life-cycle service management and operations.

The YANG model discussed in this document basically provides the following:

- Characteristics of Access Points (APs) that describe customer's end point characteristics;

- Characteristics of Virtual Network Access Points (VNAP) that describe how an AP is partitioned for multiple VNs sharing the AP and its reference to a Link Termination Point (LTP) of the Provider Edge (PE) Node;

- Characteristics of Virtual Networks (VNs) that describe the customer's VN in terms of multiple VN Members comprising a VN, multi- source and/or multi-destination characteristics of the VN Member, the VN's reference to TE-topology's Abstract Node;

The actual VN instantiation and computation is performed with Connectivity Matrices sub-module of TE-Topology Model [RFC8795] which provides TE network topology abstraction and management operation. Once TE-topology Model is used in triggering VN instantiation over the networks, TE-tunnel [I-D.ietf-teas-yang-te] Model will inevitably interact with TE-Topology model for setting up actual tunnels and LSPs under the tunnels.

Abstraction and Control of Traffic Engineered Networks (ACTN) describes a set of management and control functions used to operate one or more TE networks to construct virtual networks that can be represented to customers and that are built from abstractions of the underlying TE networks [RFC8453]. ACTN is the primary example of the usage of the VN YANG model.

Sections 2 and 3 provide the discussion of how the VN YANG model is applicable to the ACTN context where Virtual Network Service (VNS) operation is implemented for the Customer Network Controller (CNC)-Multi-Domain Service Coordinator (MSDC) interface (CMI).

The YANG model on the CMI is also known as customer service model in [RFC8309]. The YANG model discussed in this document is used to operate customer-driven VNs during the VN instantiation, VN computation, and its life-cycle service management and operations.

The VN operational state is included in the same tree as the configuration consistent with Network Management Datastore Architecture (NMDA) [RFC8342]. The origin of the data is indicated as per the origin metadata annotation.

1.1. Terminology

Refer to [RFC8453], [RFC7926], and [RFC8309] for the key terms used in this document.

1.1.1. Requirements Language

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

1.2. Tree diagram

A simplified graphical representation of the data model is used in Section 5 of this this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

1.3. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

Prefix	YANG module	Reference
vn	ietf-vn	[RFCXXXX]
yang	ietf-yang-types	[RFC6991]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
te-types	ietf-te-types	[RFC8776]
tet	ietf-te-topology	[RFC8795]

Table 1: Prefixes and corresponding YANG modules

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

2. Use-case of VN YANG Model in the ACTN context

In this section, ACTN is being used to illustrate the general usage of the VN YANG model. The model presented in this section has the following ACTN context.

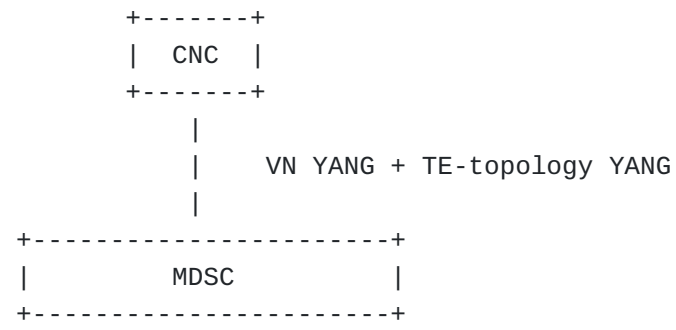


Figure 1: ACTN CMI

Both ACTN VN YANG and TE-topology models are used over the CMI to establish a VN over TE networks.

2.1. Type 1 VN

As defined in [RFC8453], a Virtual Network is a customer view of the TE network. To recapitulate VN types from [RFC8453], Type 1 VN is defined as follows:

The VN can be seen as a set of edge-to-edge abstract links (a Type 1 VN). Each abstract link is referred to as a VN member and is formed as an end-to-end tunnel across the underlying networks. Such tunnels may be constructed by recursive slicing or abstraction of paths in the underlying networks and can encompass edge points of the customer's network, access links, intra-domain paths, and inter-domain links.

If we were to create a VN where we have four VN-members as follows:

VN-Member 1	L1-L4
VN-Member 2	L1-L7
VN-Member 3	L2-L4
VN-Member 4	L3-L8

Where L1, L2, L3, L4, L7 and L8 correspond to a Customer End-Point, respectively.

This VN can be modeled as one abstract node representation as follows in Figure 2:

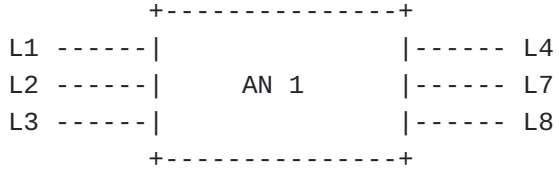


Figure 2: Abstract Node (One node topology)

Modeling a VN as one abstract node is the easiest way for customers to express their end-to-end connectivity; however, customers are not limited to express their VN only with one abstract node.

2.2. Type 2 VN

For some VN members of a VN, the customers are allowed to configure the actual path (i.e., detailed virtual nodes and virtual links) over the VN/abstract topology agreed mutually between CNC and MDSC prior to or a topology created by the MDSC as part of VN instantiation. Type 1 VN is a higher abstraction of a Type 2 VN.

If a Type 2 VN is desired for some or all of VN members of a type 1 VN (see the example in Section 2.1), the TE-topology model can provide the following abstract topology (that consists of virtual nodes and virtual links) which is built under the Type 1 VN.

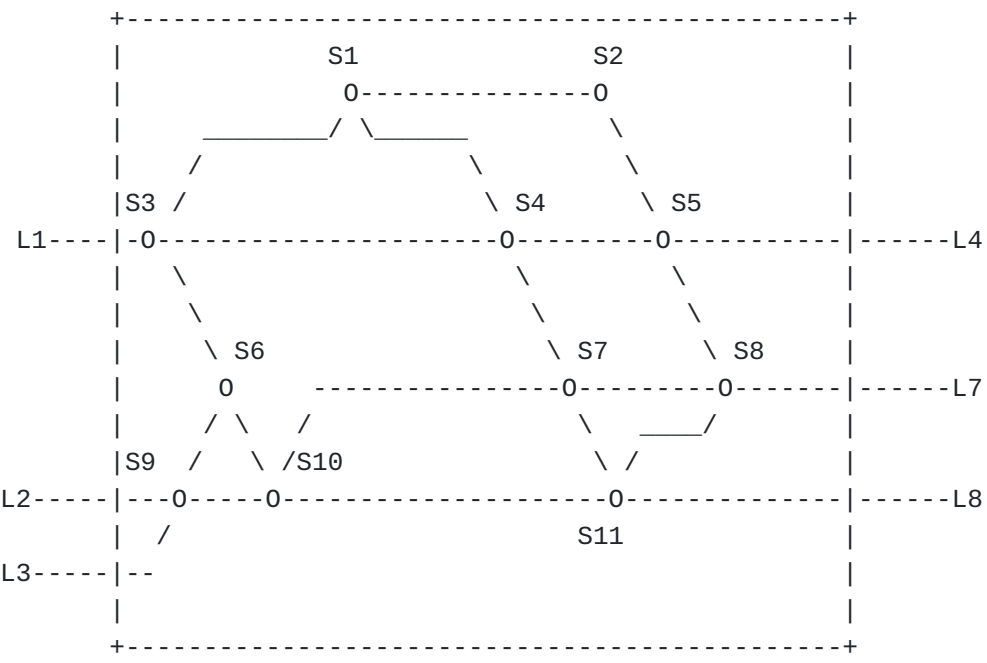


Figure 3: Type 2 topology

As you see from Figure 3, the Type 1 abstract node is depicted as a Type 1 abstract topology comprising of detailed virtual nodes and virtual links.

As an example, if VN-member 1 (L1-L4) is chosen to configure its own path over Type 2 topology, it can select, say, a path that consists of the ERO {S3,S4,S5} based on the topology and its service requirement. This capability is enacted via TE-topology configuration by the customer.

3. High-Level Control Flows with Examples

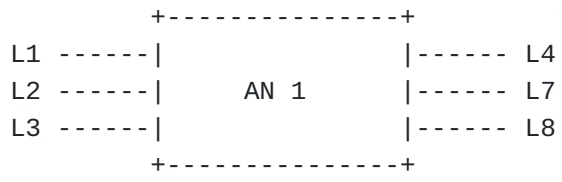
3.1. Type 1 VN Illustration

If we were to create a VN where we have four VN-members as follows:

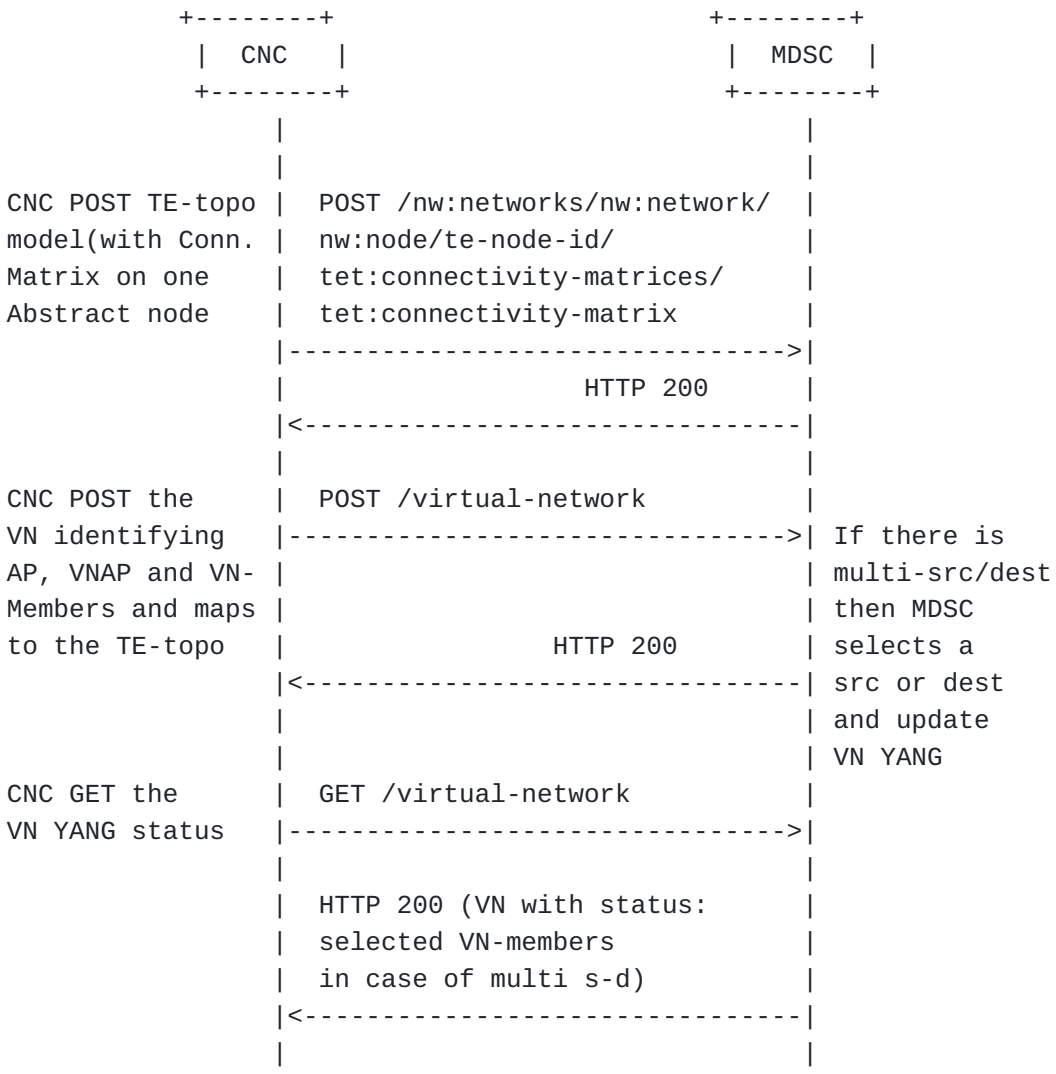
VN-Member 1	L1-L4
VN-Member 2	L1-L7
VN-Member 3	L2-L4
VN-Member 4	L3-L8

Where L1, L2, L3, L4, L7 and L8 correspond to Access Points.

This VN can be modeled as one abstract node representation as follows:



If this VN is Type 1, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using VN and TE-Topology Models.



3.2. Type 2 VN Illustration

For some VN members, the customer may want to "configure" explicit routes over the path that connects its two end-points. Let us consider the following example.

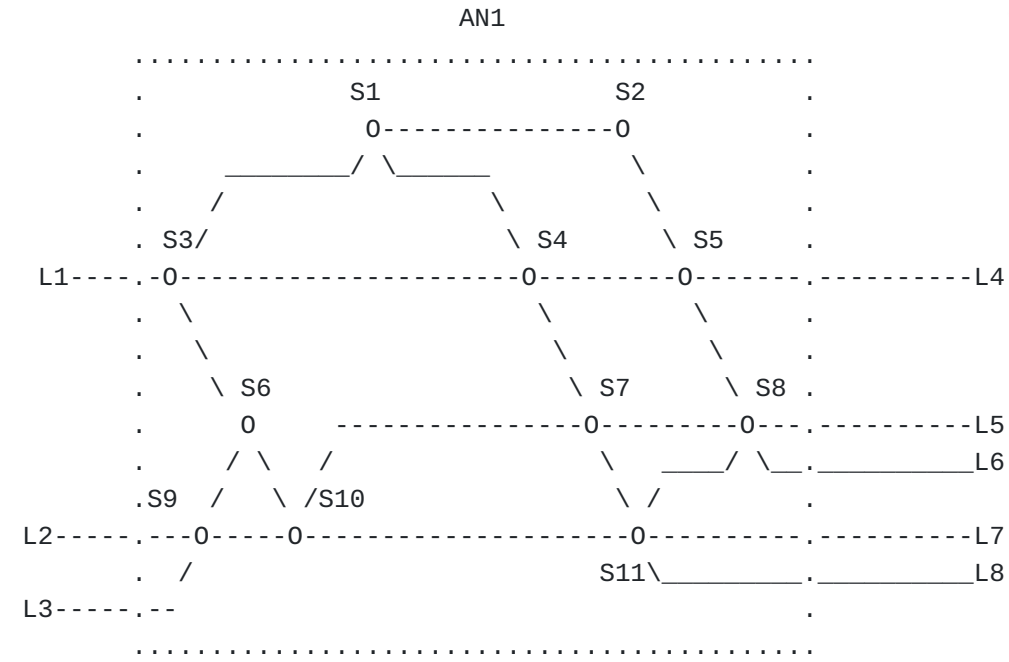
VN-Member 1 L1-L4 (via S3, S4, and S5)

VN-Member 2 L1-L7 (via S3, S4, S7 and S8)

VN-Member 3 L2-L7 (via S9, S10, and S11)

VN-Member 4 L3-L8 (via S9, S10 and S11)

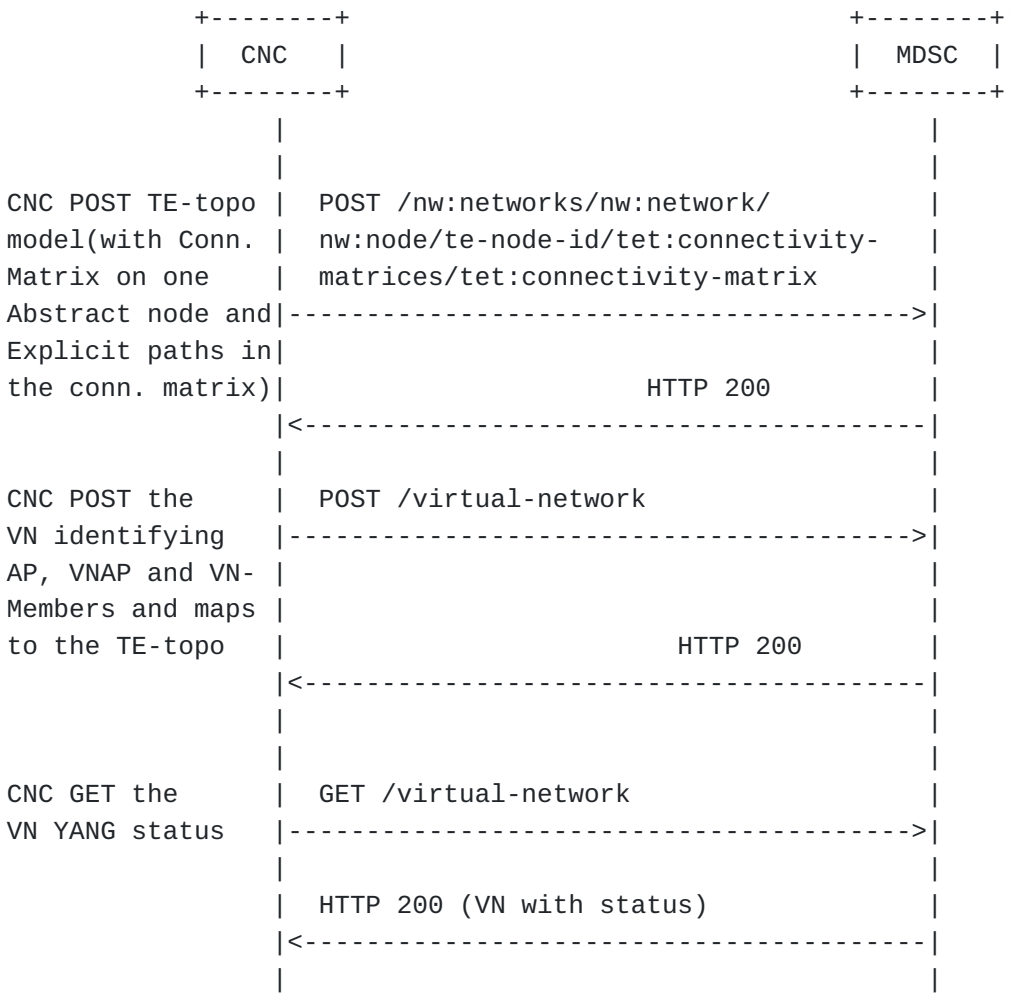
Where the following topology is the underlay for Abstraction Node 1 (AN1).



There are two options depending on whether CNC or MDSC creates the single abstract node topology.

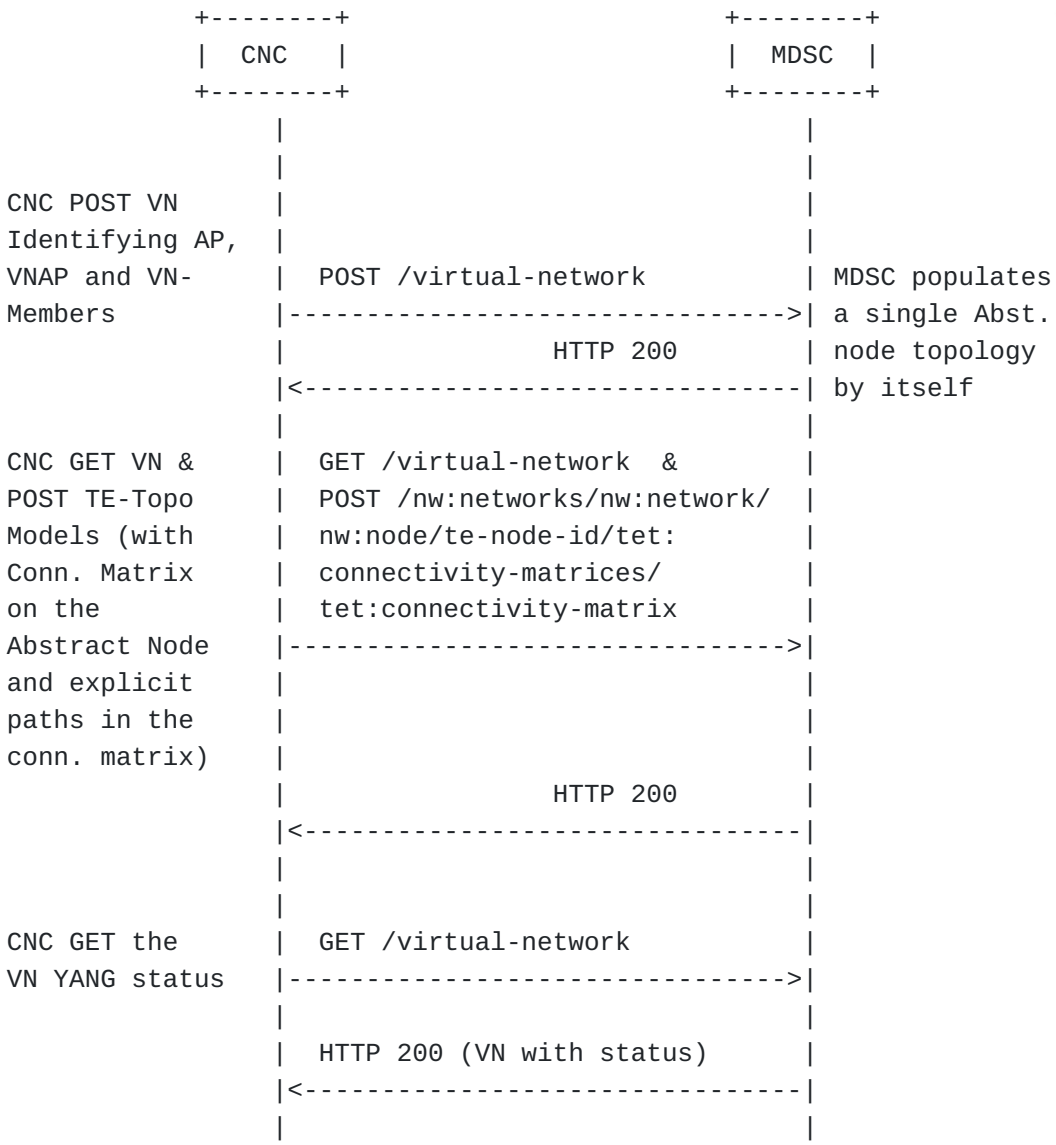
Case 1:

If CNC creates the single abstract node topology, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using VN and TE-Topology Model.



Case 2:

On the other hand, if MDSC create the single abstract node topology based VN YANG posted by the CNC, the following diagram shows the message flow between CNC and MDSC to instantiate this VN using VN and TE-Topology Models.



Section 7 provides JSON examples for both VN model and TE-topology Connectivity Matrix sub-model to illustrate how a VN can be created by the CNC making use of the VN module as well as the TE-topology Connectivity Matrix module.

3.2.1. VN and AP Usage

The customer access information may be known at the time of VN creation. A shared logical AP identifier is used between the customer and the operator to identify the access link between Customer Edge (CE) and Provider Edge (PE) . This is described in Section 6 of [RFC8453].

In some VN operations, the customer access may not be known at the initial VN creation. The VN operation allow a creation of VN with only PE identifier as well. The customer access information could be added later.

To achieve this the 'ap' container has a leaf for 'pe' node that allows AP to be created with PE information. The vn-member (and vn) could use APs that only have PE information initially.

4. VN Model Usage

4.1. Customer view of VN

The VN-YANG model allows to define a customer view, and allows the customer to communicate using the VN constructs as described in the [RFC8454]. It also allows to group the set of edge-to-edge links (i.e., VN members) under a common umbrella of VN. This allows the customer to instantiate and view the VN as one entity, making it easier for some customers to work on VN without worrying about the details of the provider based YANG models.

This is similar to the benefits of having a separate YANG model for the customer services as described in [RFC8309], which states that service models do not make any assumption of how a service is actually engineered and delivered for a customer.

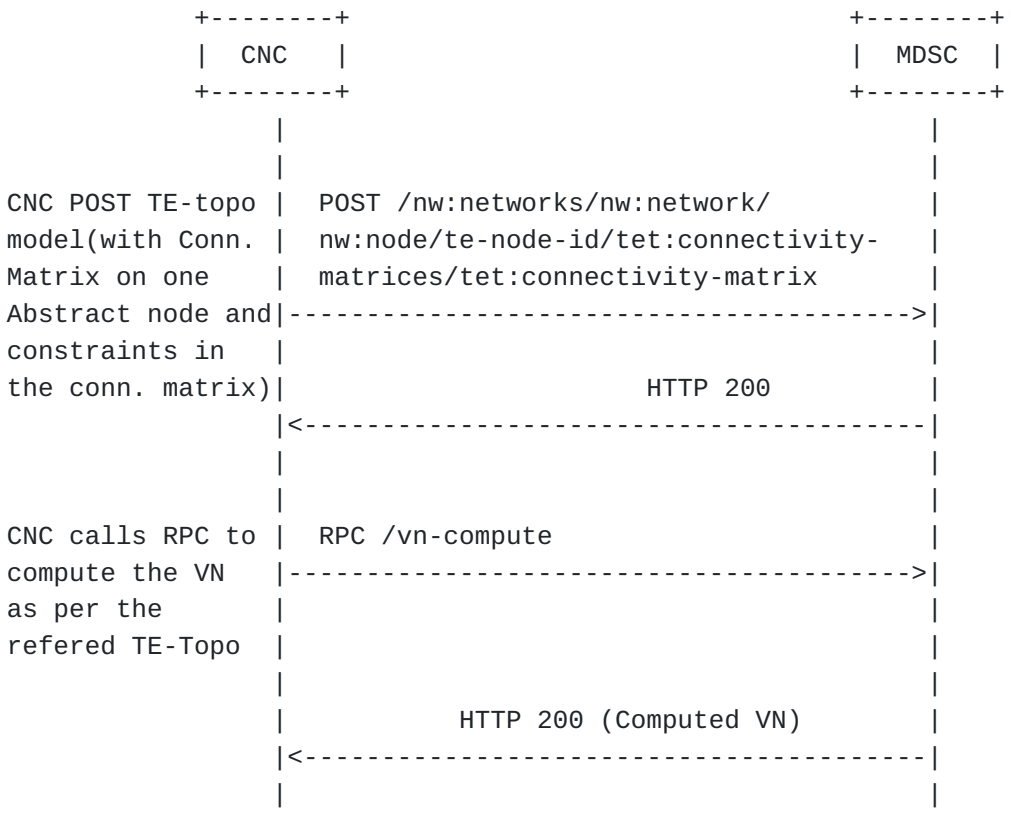
4.2. Auto-creation of VN by MDSC

The VN could be configured at the MDSC explicitly by the CNC using the VN YANG model. In some other cases, the VN is not explicitly configured, but created automatically by the MDSC based on the customer service model and local policy, even in these case the VN YANG model can be used by the CNC to learn details of the underlying VN created to meet the requirements of customer service model.

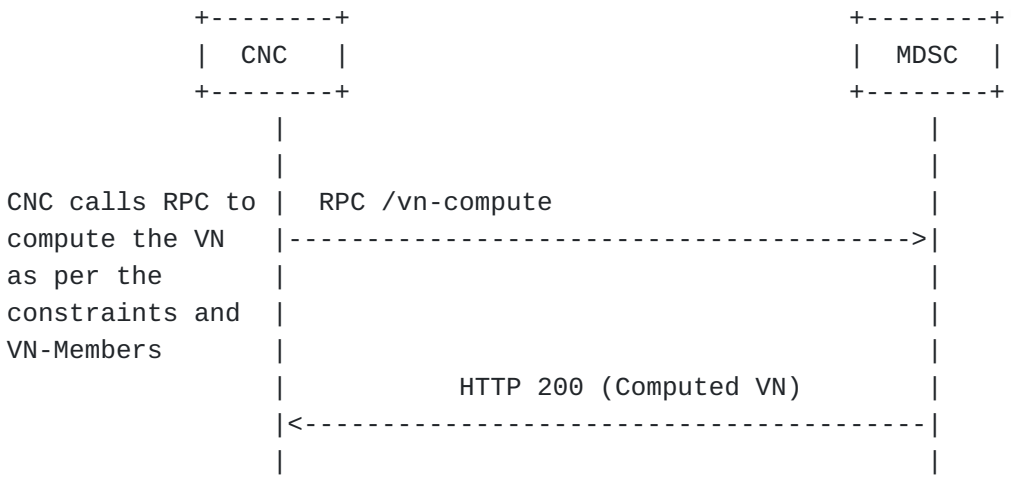
4.3. Innovative Services

4.3.1. VN Compute

VN Model supports VN compute (pre-instantiation mode) to view the full VN as a single entity before instantiation. Achieving this via path computation or "compute only" tunnel setup does not provide the same functionality.



The VN compute RPC allow you to optionally include the constraints and the optimization criteria at the VN as well as at the individual VN-member level. Thus, the RPC can be used independently to get the computed VN result without creating an abstract topology first.



In either case the output includes a reference to the single node abstract topology with each VN-member including a reference to the connectivity-matrix-id where the path properties could be found.

To achieve this the VN-compute RPC reuses the following common groupings:

- te-types:generic-path-constraints: This is used optionally in the RPC input at the VN and/or VN-member level. The VN-member level overrides the VN-level data. This also overrides any constraints in the referred abstract node in the TE topology.

- te-types:generic-path-optimization: This is used optionally in the RPC input at the VN and/or VN-member level. The VN-member level overrides the VN-level data. This also overrides any optimization in the referred abstract node in the TE topology.

- vn-member: This identifies the VN member in both RPC input and output.

- vn-policy: This is used optionally in the RPC input to apply any VN level policies.

When MDSC receives this RPC it computes the VN based on the input provided in the RPC call. This computation does not create a VN or reserve any resources in the system, it simply computes the resulting VN based on information at the MDSC or in coordination with the CNC. A single node abstract topology is used to convey the result of the each VN member as a reference to the connectivity-matrix-id. In case of error, the error information is included.

```
rpcs:
  +---x vn-compute
     +---w input
     |  +---w te-topology-identifier
     |  |  +---w provider-id?   te-global-id
     |  |  +---w client-id?     te-global-id
     |  |  +---w topology-id?   te-topology-id
     |  +---w abstract-node?
     |  |       -> /nw:networks/network/node/tet:te-node-id
     |  +---w path-constraints
     |  |  +---w te-bandwidth
     |  |  |  +---w (technology)?
     |  |  |        ...
     |  |  +---w link-protection?          identityref
     |  |  +---w setup-priority?           uint8
     |  |  +---w hold-priority?            uint8
     |  |  +---w signaling-type?           identityref
     |  |  +---w path-metric-bounds
     |  |  |  +---w path-metric-bound* [metric-type]
     |  |  |        ...
     |  |  +---w path-affinities-values
     |  |  |  +---w path-affinities-value* [usage]
     |  |  |        ...
     |  |  +---w path-affinity-names
     |  |  |  +---w path-affinity-name* [usage]
     |  |  |        ...
     |  |  +---w path-srlgs-lists
     |  |  |  +---w path-srlgs-list* [usage]
     |  |  |        ...
     |  |  +---w path-srlgs-names
     |  |  |  +---w path-srlgs-name* [usage]
     |  |  |        ...
     |  |  +---w disjointness?             te-path-disjointness
     |  +---w cos?                      te-types:te-ds-class
     |  +---w optimizations
     |  |  +---w (algorithm)?
     |  |     +--:(metric) {path-optimization-metric}?
     |  |     |     ...
     |  |     +--:(objective-function)
     |  |              {path-optimization-objective-function}?
     |  |           ...
     |  +---w vn-member-list* [vnm-id]
     |  |  +---w vnm-id                    vnm-id
     |  |  +---w src
     |  |  |  +---w src?            -> /access-point/ap/ap-id
     |  |  |  +---w src-vn-ap-id?
     |  |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
     |  |  |  +---w multi-src?      boolean {multi-src-dest}?
```

```
|  |  +---w dest
|  |  |  +---w dest?            -> /access-point/ap/ap-id
|  |  |  +---w dest-vn-ap-id?
|  |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
|  |  |  +---w multi-dest?      boolean {multi-src-dest}?
|  |  +---w connectivity-matrix-id?   leafref
|  |  +---w underlay
|  |  +---w path-constraints
|  |  |  +---w te-bandwidth
|  |  |  |     ...
|  |  |  +---w link-protection?          identityref
|  |  |  +---w setup-priority?           uint8
|  |  |  +---w hold-priority?            uint8
|  |  |  +---w signaling-type?           identityref
|  |  |  +---w path-metric-bounds
|  |  |  |     ...
|  |  |  +---w path-affinities-values
|  |  |  |     ...
|  |  |  +---w path-affinity-names
|  |  |  |     ...
|  |  |  +---w path-srlgs-lists
|  |  |  |     ...
|  |  |  +---w path-srlgs-names
|  |  |  |     ...
|  |  |  +---w disjointness?             te-path-disjointness
|  |  +---w cos?                     te-types:te-ds-class
|  |  +---w optimizations
|  |     +---w (algorithm)?
|  |           ...
|  +---w vn-level-diversity?
|          te-types:te-path-disjointness
+--ro output
   +--ro te-topology-identifier
   |  +--ro provider-id?   te-global-id
   |  +--ro client-id?     te-global-id
   |  +--ro topology-id?   te-topology-id
   +--ro abstract-node?
   |       -> /nw:networks/network/node/tet:te-node-id
   +--ro vn-member-list* [vnm-id]
      +--ro vnm-id                    vnm-id
      +--ro src
      |  +--ro src?            -> /access-point/ap/ap-id
      |  +--ro src-vn-ap-id?
      |  |       -> /access-point/ap/vn-ap/vn-ap-id
      |  +--ro multi-src?      boolean {multi-src-dest}?
      +--ro dest
      |  +--ro dest?            -> /access-point/ap/ap-id
      |  +--ro dest-vn-ap-id?
      |  |       -> /access-point/ap/vn-ap/vn-ap-id
```

```
|  +--ro multi-dest?      boolean {multi-src-dest}?
+--ro connectivity-matrix-id?   leafref
+--ro underlay
+--ro if-selected?              boolean
|       {multi-src-dest}?
+--ro compute-status?           vn-compute-status
+--ro error-info
   +--ro error-description?   string
   +--ro error-timestamp?     yang:date-and-time
   +--ro error-reason?        identityref
```

4.3.2. Multi-sources and Multi-destinations

In creating a virtual network, the list of sources or destinations or both may not be pre-determined by the customer. For instance, for a given source, there may be a list of multiple-destinations to which the optimal destination may be chosen depending on the network resource situations. Likewise, for a given destination, there may also be multiple-sources from which the optimal source may be chosen. In some cases, there may be a pool of multiple sources and destinations from which the optimal source-destination may be chosen. The following YANG module is shown for describing source container and destination container. The following YANG tree shows how to model multi-sources and multi-destinations.

```
module: ietf-vn
  +--rw virtual-network
     +--rw vn* [vn-id]
        +--rw vn-id                      vn-id
        +--rw te-topology-identifier
        |  +--rw provider-id?   te-global-id
        |  +--rw client-id?     te-global-id
        |  +--rw topology-id?   te-topology-id
        +--rw abstract-node?
        |       -> /nw:networks/network/node/tet:te-node-id
        +--rw vn-member* [vnm-id]
        |  +--rw vnm-id                    vnm-id
        |  +--rw src
        |  |  +--rw src?            -> /access-point/ap/ap-id
        |  |  +--rw src-vn-ap-id?
        |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
        |  |  +--rw multi-src?      boolean {multi-src-dest}?
        |  +--rw dest
        |  |  +--rw dest?            -> /access-point/ap/ap-id
        |  |  +--rw dest-vn-ap-id?
        |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
        |  |  +--rw multi-dest?      boolean {multi-src-dest}?
        |  +--rw connectivity-matrix-id?   leafref
        |  +--rw underlay
        |  +--ro oper-status?              te-types:te-oper-status
        +--ro if-selected?              boolean {multi-src-dest}?
        +--rw admin-status?             te-types:te-admin-status
        +--ro oper-status?              te-types:te-oper-status
        +--rw vn-level-diversity?       te-types:te-path-disjointness
```

4.3.3. Others

The VN YANG model can be easily augmented to support the mapping of VN to the Services such as L3SM and L2SM as described in [I-D.ietf-teas-te-service-mapping-yang].

The VN YANG model can be extended to support telemetry, performance monitoring and network autonomics as described in [I-D.ietf-teas-actn-pm-telemetry-autonomics].

Note that the YANG model is tightly coupled with the TE Topology model [RFC8795]. Any underlay technology not supported by [RFC8795] is also not supported by this model. The model does include an empty container called "underlay" that can be augmented. For example the SR-policy information can be augmented for the SR underlay by a future model.

Apart from the te-types:generic-path-constraints and te-types:generic-path-optimization, an additional leaf cos for class of service [RFC4124] is added to represent the Class-Type of traffic to be used as one of the path constraints.

4.3.4. Summary

This section summarizes the innovative service features of the VN YANG.

*Maintenance of AP and VNAP along with VN

*VN construct to group of edge-to-edge links

*VN Compute (pre-instantiate)

*Multi-Source / Multi-Destination

*Ability to support various VN and VNS Types

-VN Type 1: Customer configures the VN as a set of VN Members. No other details need to be set by customer, making for a simplified operations for the customer.

-VN Type 2: Along with VN Members, the customer could also provide an abstract topology, this topology is provided by the Abstract TE Topology YANG Model.

5. VN YANG Model (Tree Structure)

```
module: ietf-vn
  +--rw access-point
  |  +--rw ap* [ap-id]
  |     +--rw ap-id            ap-id
  |     +--rw pe?
  |     |       -> /nw:networks/network/node/tet:te-node-id
  |     +--rw max-bandwidth?   te-types:te-bandwidth
  |     +--rw avl-bandwidth?   te-types:te-bandwidth
  |     +--rw vn-ap* [vn-ap-id]
  |        +--rw vn-ap-id         ap-id
  |        +--rw vn?              -> /virtual-network/vn/vn-id
  |        +--rw abstract-node?
  |        |       -> /nw:networks/network/node/tet:te-node-id
  |        +--rw ltp?             leafref
  |        +--ro max-bandwidth?   te-types:te-bandwidth
  +--rw virtual-network
     +--rw vn* [vn-id]
        +--rw vn-id                      vn-id
        +--rw te-topology-identifier
        |  +--rw provider-id?   te-global-id
        |  +--rw client-id?     te-global-id
        |  +--rw topology-id?   te-topology-id
        +--rw abstract-node?
        |       -> /nw:networks/network/node/tet:te-node-id
        +--rw vn-member* [vnm-id]
        |  +--rw vnm-id                    vnm-id
        |  +--rw src
        |  |  +--rw src?            -> /access-point/ap/ap-id
        |  |  +--rw src-vn-ap-id?
        |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
        |  |  +--rw multi-src?      boolean {multi-src-dest}?
        |  +--rw dest
        |  |  +--rw dest?            -> /access-point/ap/ap-id
        |  |  +--rw dest-vn-ap-id?
        |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
        |  |  +--rw multi-dest?      boolean {multi-src-dest}?
        |  +--rw connectivity-matrix-id?   leafref
        |  +--rw underlay
        |  +--ro oper-status?              te-types:te-oper-status
        +--ro if-selected?              boolean {multi-src-dest}?
        +--rw admin-status?             te-types:te-admin-status
        +--ro oper-status?              te-types:te-oper-status
        +--rw vn-level-diversity?       te-types:te-path-disjointness

  rpcs:
    +---x vn-compute
       +---w input
       |  +---w te-topology-identifier
       |  |  +---w provider-id?   te-global-id
```

```
|  |  +---w client-id?     te-global-id
|  |  +---w topology-id?   te-topology-id
|  +---w abstract-node?
|  |       -> /nw:networks/network/node/tet:te-node-id
|  +---w path-constraints
|  |  +---w te-bandwidth
|  |  |  +---w (technology)?
|  |  |        ...
|  |  +---w link-protection?          identityref
|  |  +---w setup-priority?           uint8
|  |  +---w hold-priority?            uint8
|  |  +---w signaling-type?           identityref
|  |  +---w path-metric-bounds
|  |  |  +---w path-metric-bound* [metric-type]
|  |  |        ...
|  |  +---w path-affinities-values
|  |  |  +---w path-affinities-value* [usage]
|  |  |        ...
|  |  +---w path-affinity-names
|  |  |  +---w path-affinity-name* [usage]
|  |  |        ...
|  |  +---w path-srlgs-lists
|  |  |  +---w path-srlgs-list* [usage]
|  |  |        ...
|  |  +---w path-srlgs-names
|  |  |  +---w path-srlgs-name* [usage]
|  |  |        ...
|  |  +---w disjointness?             te-path-disjointness
|  +---w cos?                      te-types:te-ds-class
|  +---w optimizations
|  |  +---w (algorithm)?
|  |     +--:(metric) {path-optimization-metric}?
|  |     |     ...
|  |     +--:(objective-function)
|  |              {path-optimization-objective-function}?
|  |           ...
|  +---w vn-member-list* [vnm-id]
|  |  +---w vnm-id                    vnm-id
|  |  +---w src
|  |  |  +---w src?            -> /access-point/ap/ap-id
|  |  |  +---w src-vn-ap-id?
|  |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
|  |  |  +---w multi-src?      boolean {multi-src-dest}?
|  |  +---w dest
|  |  |  +---w dest?            -> /access-point/ap/ap-id
|  |  |  +---w dest-vn-ap-id?
|  |  |  |       -> /access-point/ap/vn-ap/vn-ap-id
|  |  |  +---w multi-dest?      boolean {multi-src-dest}?
|  |  +---w connectivity-matrix-id?   leafref
```

```
|  |  +---w underlay
|  |  +---w path-constraints
|  |  |  +---w te-bandwidth
|  |  |  |     ...
|  |  |  +---w link-protection?          identityref
|  |  |  +---w setup-priority?           uint8
|  |  |  +---w hold-priority?            uint8
|  |  |  +---w signaling-type?           identityref
|  |  |  +---w path-metric-bounds
|  |  |  |     ...
|  |  |  +---w path-affinities-values
|  |  |  |     ...
|  |  |  +---w path-affinity-names
|  |  |  |     ...
|  |  |  +---w path-srlgs-lists
|  |  |  |     ...
|  |  |  +---w path-srlgs-names
|  |  |  |     ...
|  |  |  +---w disjointness?             te-path-disjointness
|  |  +---w cos?                      te-types:te-ds-class
|  |  +---w optimizations
|  |     +---w (algorithm)?
|  |           ...
|  +---w vn-level-diversity?
|          te-types:te-path-disjointness
+--ro output
   +--ro te-topology-identifier
   |  +--ro provider-id?   te-global-id
   |  +--ro client-id?     te-global-id
   |  +--ro topology-id?   te-topology-id
   +--ro abstract-node?
   |       -> /nw:networks/network/node/tet:te-node-id
   +--ro vn-member-list* [vnm-id]
      +--ro vnm-id                    vnm-id
      +--ro src
      |  +--ro src?            -> /access-point/ap/ap-id
      |  +--ro src-vn-ap-id?
      |  |       -> /access-point/ap/vn-ap/vn-ap-id
      |  +--ro multi-src?      boolean {multi-src-dest}?
      +--ro dest
      |  +--ro dest?            -> /access-point/ap/ap-id
      |  +--ro dest-vn-ap-id?
      |  |       -> /access-point/ap/vn-ap/vn-ap-id
      |  +--ro multi-dest?      boolean {multi-src-dest}?
      +--ro connectivity-matrix-id?   leafref
      +--ro underlay
      +--ro if-selected?              boolean
      |       {multi-src-dest}?
      +--ro compute-status?           vn-compute-status
```

```
+--ro error-info
   +--ro error-description?   string
   +--ro error-timestamp?     yang:date-and-time
   +--ro error-reason?        identityref
```

6. VN YANG Model

The YANG model is as follows:

```
<CODE BEGINS> file "ietf-vn@2022-03-07.yang"

module ietf-vn {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-vn";
  prefix vn;

  /* Import network */

  import ietf-yang-types {
    prefix yang;
    reference
      "RFC 6991: Common YANG Data Types";
  }
  import ietf-network {
    prefix nw;
    reference
      "RFC 8345: A YANG Data Model for Network Topologies";
  }

  /* Import network topology */

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

  /* Import TE Common types */

  import ietf-te-types {
    prefix te-types;
    reference
      "RFC 8776: Common YANG Data Types for Traffic Engineering";
  }

  /* Import TE Topology */

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

  organization
    "IETF Traffic Engineering Architecture and Signaling (TEAS)
     Working Group";
  contact
    "WG Web:  <https://datatracker.ietf.org/wg/teas/about/>
```

```
   WG List:  <mailto:teas@ietf.org>
   Editor: Young Lee <younglee.tx@gmail.com>
         : Dhruv Dhody <dhruv.ietf@gmail.com>";
description
  "This module contains a YANG module for the Virtual Network
   (VN). It describes a VN operation module that takes place
   in the context of the Customer Network Controller (CNC)-
   Multi-Domain Service Coordinator (MSDC) interface (CMI) of
   the Abstraction and Control of Traffic Engineered Networks
   (ACTN) architecture where the CNC is the actor of a VN
   Instantiation/modification/deletion as per RFC 8453.

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   authors of the code.  All rights reserved.

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   without modification, is permitted pursuant to, and subject to
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   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.

   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 (RFC 2119) (RFC 8174) when, and only when,
   they appear in all capitals, as shown here.";

revision 2022-03-07 {
  description
    "initial version.";
  reference
    "RFC XXXX: A YANG Data Model for VN Operation";
}

/* Features */

feature multi-src-dest {
  description
    "Support for selection of one src or destination
     among multiple.";
  reference
    "RFC 8453: Framework for Abstraction and Control of TE
     Networks (ACTN)";
}

/* Typedef */
```

```
typedef vn-id {
  type string;
  description
    "Defines a type of Virtual Network (VN) identifier.";
}

typedef ap-id {
  type string;
  description
    "Defines a type of Access Point (AP) identifier.";
}

typedef vnm-id {
  type string;
  description
    "Defines a type of VN member identifier.";
}

typedef vn-compute-status {
  type te-types:te-common-status;
  description
    "Defines a type representing the VN compute status. Note
     that all status apart from up and down are considered as
     unknown.";
}

/* identities */

identity vn-computation-error-reason {
  description
    "Base identity for VN computation error reasons.";
}

identity vn-computation-error-not-ready {
  base vn-computation-error-reason;
  description
    "VN computation has failed because the MDSC is not
     ready";
}

identity vn-computation-error-no-cnc {
  base vn-computation-error-reason;
  description
    "VN computation has failed because one or more dependent
     CNC are unavailable.";
}

identity vn-computation-error-no-resource {
  base vn-computation-error-reason;
```

```
  description
    "VN computation has failed because there is no
     available resource in one or more domains.";
}

identity vn-computation-error-path-not-found {
  base vn-computation-error-reason;
  description
    "VN computation failed as no path found.";
}

identity vn-computation-ap-unknown {
  base vn-computation-error-reason;
  description
    "VN computation failed as source or destination AP not
     known.";
}

/* Groupings */

grouping vn-ap {
  description
    "VNAP related information";
  leaf vn-ap-id {
    type ap-id;
    description
      "A unique identifier for the referred VNAP";
  }
  leaf vn {
    type leafref {
      path "/virtual-network/vn/vn-id";
    }
    description
      "A reference to the VN";
  }
  leaf abstract-node {
    type leafref {
      path "/nw:networks/nw:network/nw:node/tet:te-node-id";
    }
    description
      "A reference to the abstract node in TE Topology that
       represent the VN";
  }
  leaf ltp {
    type leafref {
      path "/nw:networks/nw:network/nw:node/"
         + "nt:termination-point/tet:te-tp-id";
    }
    description
```

```
      "A reference to Link Termination Point (LTP) in the
       TE-topology";
    reference
      "RFC 8795: YANG Data Model for Traffic Engineering (TE)
       Topologies";
  }
  leaf max-bandwidth {
    type te-types:te-bandwidth;
    config false;
    description
      "The max bandwidth of the VNAP";
  }
  reference
    "RFC 8453: Framework for Abstraction and Control of TE
     Networks (ACTN), Section 6";
} //vn-ap

grouping access-point {
  description
    "AP related information";
  leaf ap-id {
    type ap-id;
    description
      "A unique identifier for the referred access point";
  }
  leaf pe {
    type leafref {
      path "/nw:networks/nw:network/nw:node/tet:te-node-id";
    }
    description
      "A reference to the PE node in the native TE Topology";
  }
  leaf max-bandwidth {
    type te-types:te-bandwidth;
    description
      "The max bandwidth of the AP";
  }
  leaf avl-bandwidth {
    type te-types:te-bandwidth;
    description
      "The available bandwidth of the AP";
  }
  /*add details and any other properties of AP,
  not associated by a VN
  CE port, PE port etc.
   */
  list vn-ap {
    key "vn-ap-id";
    uses vn-ap;
```

```
    description
      "List of VNAP in this AP";
  }
  reference
    "RFC 8453: Framework for Abstraction and Control of TE
     Networks (ACTN), Section 6";
} //access-point

grouping vn-member {
  description
    "The vn-member is described by this grouping";
  leaf vnm-id {
    type vnm-id;
    description
      "A vn-member identifier";
  }
  container src {
    description
      "The source of VN Member";
    leaf src {
      type leafref {
        path "/access-point/ap/ap-id";
      }
      description
        "A reference to source AP";
    }
    leaf src-vn-ap-id {
      type leafref {
        path "/access-point/ap/vn-ap/vn-ap-id";
      }
      description
        "A reference to source VNAP";
    }
    leaf multi-src {
      if-feature "multi-src-dest";
      type boolean;
      default "false";
      description
        "Is the source part of multi-source, where
         only one of the source is enabled";
    }
  }
  container dest {
    description
      "the destination of VN Member";
    leaf dest {
      type leafref {
        path "/access-point/ap/ap-id";
      }
```

```
      description
        "A reference to destination AP";
    }
    leaf dest-vn-ap-id {
      type leafref {
        path "/access-point/ap/vn-ap/vn-ap-id";
      }
      description
        "A reference to dest VNAP";
    }
    leaf multi-dest {
      if-feature "multi-src-dest";
      type boolean;
      default "false";
      description
        "Is destination part of multi-destination, where only one
         of the destination is enabled";
    }
  }
  leaf connectivity-matrix-id {
    type leafref {
      path "/nw:networks/nw:network/nw:node/tet:te/"
         + "tet:te-node-attributes/"
         + "tet:connectivity-matrices/"
         + "tet:connectivity-matrix/tet:id";
    }
    description
      "A reference to connectivity-matrix";
    reference
      "RFC 8795: YANG Data Model for Traffic Engineering (TE)
       Topologies";
  }
  container underlay {
    description
      "An empty container that can be augmented with underlay
       technology information not supported by RFC 8795 (for
       example - Segement Routing (SR). ";
  }
  reference
    "RFC 8454: Information Model for Abstraction and Control of TE
     Networks (ACTN)";
} //vn-member

grouping vn-policy {
  description
    "policy for VN-level diverisity";
  leaf vn-level-diversity {
    type te-types:te-path-disjointness;
    description
```

```
      "The type of disjointness on the VN level (i.e., across all
       VN members)";
  }
}

/* Configuration data nodes */

container access-point {
  description
    "AP configurations";
  list ap {
    key "ap-id";
    description
      "access-point identifier";
    uses access-point {
      description
        "The access-point information";
    }
  }
  reference
    "RFC 8453: Framework for Abstraction and Control of TE
     Networks (ACTN), Section 6";
}
container virtual-network {
  description
    "VN configurations";
  list vn {
    key "vn-id";
    description
      "A virtual network is identified by a vn-id";
    leaf vn-id {
      type vn-id;
      description
        "A unique VN identifier";
    }
    /*An optional identifier to the TE Topology Model
      where the abstract nodes and links of the Topology
      can be found for Type 2 VNS*/
    uses te-types:te-topology-identifier;
    leaf abstract-node {
      type leafref {
        path "/nw:networks/nw:network/nw:node/tet:te-node-id";
      }
      description
        "A reference to the abstract node in TE Topology";
    }
    list vn-member {
      key "vnm-id";
      description
```

```
        "List of vn-members in a VN";
      uses vn-member;
      leaf oper-status {
        type te-types:te-oper-status;
        config false;
        description
          "The vn-member operational state.";
      }
    }
    leaf if-selected {
      if-feature "multi-src-dest";
      type boolean;
      default "false";
      config false;
      description
        "Is the vn-member is selected among the multi-src/dest
         options";
    }
    leaf admin-status {
      type te-types:te-admin-status;
      default "up";
      description
        "VN administrative state.";
    }
    leaf oper-status {
      type te-types:te-oper-status;
      config false;
      description
        "VN operational state.";
    }
    uses vn-policy;
  } //vn
  reference
    "RFC 8453: Framework for Abstraction and Control of TE
     Networks (ACTN)";
} //vn

/* RPC */

rpc vn-compute {
  description
    "The VN computation without actual instantiation. This is
     used by the CNC to get the VN results without actually
     creating it in the network.

     The input could include a reference to the single node
     abstract topology. It could optionally also include
     constraints and optimization criteria. The computation
     is done based on the list of VN-members.
```

```
   The output includes a reference to the single node
   abstract topology with each VN-member including a
   reference to the connectivity-matrix-id where the
   path properties could be found. Error information is
   also included.";
 input {
   uses te-types:te-topology-identifier;
   leaf abstract-node {
     type leafref {
       path "/nw:networks/nw:network/nw:node/tet:te-node-id";
     }
     description
       "A reference to the abstract node in TE Topology";
   }
   uses te-types:generic-path-constraints;
   leaf cos {
     type te-types:te-ds-class;
     description
       "The class of service";
   }
   uses te-types:generic-path-optimization;
   list vn-member-list {
     key "vnm-id";
     description
       "List of VN-members in a VN";
     uses vn-member;
     uses te-types:generic-path-constraints;
     leaf cos {
       type te-types:te-ds-class;
       description
         "The class of service";
       reference
         "RFC 4124: Protocol Extensions for Support of
          Diffserv-aware MPLS Traffic Engineering,
          Section 4.3.1";
     }
     uses te-types:generic-path-optimization;
   }
   uses vn-policy;
 }
 output {
   uses te-types:te-topology-identifier;
   leaf abstract-node {
     type leafref {
       path "/nw:networks/nw:network/nw:node/tet:te-node-id";
     }
     description
       "A reference to the abstract node in TE Topology";
```

```
      }
      list vn-member-list {
        key "vnm-id";
        description
          "List of VN-members in a VN";
        uses vn-member;
        leaf if-selected {
          if-feature "multi-src-dest";
          type boolean;
          default "false";
          description
            "Is the vn-member is selected among the multi-src/dest
             options";
          reference
            "RFC 8453: Framework for Abstraction and Control of TE
             Networks (ACTN), Section 7";
        }
        leaf compute-status {
          type vn-compute-status;
          description
            "The VN-member compute state.";
        }
        container error-info {
          description
            "Error information related to the VN member";
          leaf error-description {
            type string;
            description
              "Textual representation of the error occurred during
               VN compute.";
          }
          leaf error-timestamp {
            type yang:date-and-time;
            description
              "Timestamp of the attempt.";
          }
          leaf error-reason {
            type identityref {
              base vn-computation-error-reason;
            }
            description
              "Reason for the VN computation error.";
          }
        }
      }
    }
  } //vn-compute

}
```

<CODE ENDS>

7. JSON Example

This section provides json implementation examples as to how VN YANG model and TE topology model are used together to instantiate virtual networks.

The example in this section includes following VN

*VN1 (Type 1): Which maps to the single node topology abstract1 (node D1) and consist of VN Members 104 (L1 to L4), 107 (L1 to L7), 204 (L2 to L4), 308 (L3 to L8) and 108 (L1 to L8). We also show how disjointness (node, link, srlg) is supported in the example on the global level (i.e., connectivity matrices level).

*VN2 (Type 2): Which maps to the single node topology abstract2 (node D2), this topology has an underlay topology (absolute) (see figure in section 3.2). This VN has a single VN member 105 (L1 to L5) and an underlay path (S4 and S7) has been set in the connectivity matrix of abstract2 topology;

*VN3 (Type 1): This VN has a multi-source, multi-destination feature enable for VN Member 104 (L1 to L4)/107 (L1 to L7) {multi-src} and VN Member 204 (L2 to L4)/304 (L3 to L4) {multi-dest} usecase. The selected VN-member is known via the field "if-selected" and the corresponding connectivity-matrix-id.

Note that the VN YANG model also include the AP and VNAP which shows various VN using the same AP.

7.1. VN JSON

```
{
  "access-point": {
    "ap": [
      {
        "ap-id": "101",
        "vn-ap": [
          {
            "vn-ap-id": "10101",
            "vn": "1",
            "abstract-node": "D1",
            "ltp": "1-0-1"
          },
          {
            "vn-ap-id": "10102",
            "vn": "2",
            "abstract-node": "D2",
            "ltp": "1-0-1"
          },
          {
            "vn-ap-id": "10103",
            "vn": "3",
            "abstract-node": "D3",
            "ltp": "1-0-1"
          }
        ]
      },
      {
        "ap-id": "202",
        "vn-ap": [
          {
            "vn-ap-id": "20201",
            "vn": "1",
            "abstract-node": "D1",
            "ltp": "2-0-2"
          }
        ]
      },
      {
        "ap-id": "303",
        "vn-ap": [
          {
            "vn-ap-id": "30301",
            "vn": "1",
            "abstract-node": "D1",
            "ltp": "3-0-3"
          },
          {
            "vn-ap-id": "30303",
            "vn": "3",
```

```
      "abstract-node": "D3",
      "ltp": "3-0-3"
    }
  ]
},
{
  "ap-id": "440",
  "vn-ap": [
    {
      "vn-ap-id": "44001",
      "vn": "1",
      "abstract-node": "D1",
      "ltp": "4-4-0"
    }
  ]
},
{
  "ap-id": "550",
  "vn-ap": [
    {
      "vn-ap-id": "55002",
      "vn": "2",
      "abstract-node": "D2",
      "ltp": "5-5-0"
    }
  ]
},
{
  "ap-id": "770",
  "vn-ap": [
    {
      "vn-ap-id": "77001",
      "vn": "1",
      "abstract-node": "D1",
      "ltp": "7-7-0"
    },
    {
      "vn-ap-id": "77003",
      "vn": "3",
      "abstract-node": "D3",
      "ltp": "7-7-0"
    }
  ]
},
{
  "ap-id": "880",
  "vn-ap": [
    {
      "vn-ap-id": "88001",
```

```
          "vn": "1",
          "abstract-node": "D1",
          "ltp": "8-8-0"
        },
        {
          "vn-ap-id": "88003",
          "vn": "3",
          "abstract-node": "D3",
          "ltp": "8-8-0"
        }
      ]
    }
  ]
},
"virtual-network": {
  "vn": [
    {
      "vn-id": "1",
      "te-topology-identifier": {
        "topology-id": "abstract1"
      },
      "abstract-node": "D1",
      "vn-member": [
        {
          "vnm-id": "104",
          "src": {
            "src": "101",
            "src-vn-ap-id": "10101"
          },
          "dest": {
            "dest": "440",
            "dest-vn-ap-id": "44001"
          },
          "connectivity-matrix-id": "104"
        },
        {
          "vnm-id": "107",
          "src": {
            "src": "101",
            "src-vn-ap-id": "10101"
          },
          "dest": {
            "dest": "770",
            "dest-vn-ap-id": "77001"
          },
          "connectivity-matrix-id": "107"
        },
        {
          "vnm-id": "204",
```

```
      "src": {
        "src": "202",
        "dest-vn-ap-id": "20401"
      },
      "dest": {
        "dest": "440",
        "dest-vn-ap-id": "44001"
      },
      "connectivity-matrix-id": "204"
    },
    {
      "vnm-id": "308",
      "src": {
        "src": "303",
        "src-vn-ap-id": "30301"
      },
      "dest": {
        "dest": "880",
        "src-vn-ap-id": "88001"
      },
      "connectivity-matrix-id": "308"
    },
    {
      "vnm-id": "108",
      "src": {
        "src": "101",
        "src-vn-ap-id": "10101"
      },
      "dest": {
        "dest": "880",
        "dest-vn-ap-id": "88001"
      },
      "connectivity-matrix-id": "108"
    }
  ]
},
{
  "vn-id": "2",
  "te-topology-identifier": {
    "topology-id": "abstract2"
  },
  "abstract-node": "D2",
  "vn-member": [
    {
      "vnm-id": "105",
      "src": {
        "src": "101",
        "src-vn-ap-id": "10102"
      },
```

```
      "dest": {
        "dest": "550",
        "dest-vn-ap-id": "55002"
      },
      "connectivity-matrix-id": "105"
    }
  ]
},
{
  "vn-id": "3",
  "te-topology-identifier": {
    "topology-id": "abstract3"
  },
  "abstract-node": "D3",
  "vn-member": [
    {
      "vnm-id": "104",
      "src": {
        "src": "101"
      },
      "dest": {
        "dest": "440",
        "multi-dest": true
      }
    },
    {
      "vnm-id": "107",
      "src": {
        "src": "101",
        "src-vn-ap-id": "10103"
      },
      "dest": {
        "dest": "770",
        "dest-vn-ap-id": "77003",
        "multi-dest": true
      },
      "connectivity-matrix-id": "107",
      "if-selected": true
    },
    {
      "vnm-id": "204",
      "src": {
        "src": "202",
        "multi-src": true
      },
      "dest": {
        "dest": "440"
      }
    },
```

```
          {
            "vnm-id": "304",
            "src": {
              "src": "303",
              "src-vn-ap-id": "30303",
              "multi-src": true
            },
            "dest": {
              "dest": "440",
              "src-vn-ap-id": "44003"
            },
            "connectivity-matrix-id": "304",
            "if-selected": true
          }
        ]
      }
    ]
  }
}
```

7.2. TE-topology JSON

```
{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {}
        },
        "network-id": "abstract1",
        "te-topology-identifier": {
          "provider-id": 0,
          "client-id": 0,
          "topology-id": "abstract1"
        },
        "node": [
          {
            "node-id": "D1",
            "te-node-id": "2.0.1.1",
            "te": {
              "te-node-attributes": {
                "domain-id": 1,
                "is-abstract": [
                  null
                ],
                "connectivity-matrices": {
                  "is-allowed": true,
                  "path-constraints": {
                    "te-bandwidth": {
                      "generic": "0x1p10"
                    },
                    "disjointness": "node link srlg"
                  },
                  "connectivity-matrix": [
                    {
                      "id": 104,
                      "from": {
                        "tp-ref": "1-0-1"
                      },
                      "to": {
                        "tp-ref": "4-4-0"
                      }
                    },
                    {
                      "id": 107,
                      "from": {
                        "tp-ref": "1-0-1"
                      },
                      "to": {
                        "tp-ref": "7-7-0"
```

```
        }
      },
      {
        "id": 204,
        "from": {
          "tp-ref": "2-0-2"
        },
        "to": {
          "tp-ref": "4-4-0"
        }
      },
      {
        "id": 308,
        "from": {
          "tp-ref": "3-0-3"
        },
        "to": {
          "tp-ref": "8-8-0"
        }
      },
      {
        "id": 108,
        "from": {
          "tp-ref": "1-0-1"
        },
        "to": {
          "tp-ref": "8-8-0"
        }
      }
    ]
  }
},
"tunnel-termination-point": [
  {
    "name": "1-0-1",
    "tunnel-tp-id": 10001,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "1-1-0",
    "tunnel-tp-id": 10100,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "2-0-2",
    "tunnel-tp-id": 20002,
    "switching-capability": "switching-otn",
```

```
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "2-2-0",
  "tunnel-tp-id": 20200,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "3-0-3",
  "tunnel-tp-id": 30003,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "3-3-0",
  "tunnel-tp-id": 30300,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "4-0-4",
  "tunnel-tp-id": 40004,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "4-4-0",
  "tunnel-tp-id": 40400,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-0-5",
  "tunnel-tp-id": 50005,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-5-0",
  "tunnel-tp-id": 50500,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "6-0-6",
  "tunnel-tp-id": 60006,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
```

```
          },
          {
            "name": "6-6-0",
            "tunnel-tp-id": 60600,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          },
          {
            "name": "7-0-7",
            "tunnel-tp-id": 70007,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          },
          {
            "name": "7-7-0",
            "tunnel-tp-id": 70700,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          },
          {
            "name": "8-0-8",
            "tunnel-tp-id": 80008,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          },
          {
            "name": "8-8-0",
            "tunnel-tp-id": 80800,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ]
},
{
  "network-types": {
    "te-topology": {}
  },
  "network-id": "abstract2",
  "te-topology-identifier": {
    "provider-id": 0,
    "client-id": 0,
    "topology-id": "abstract2"
  },
  "node": [
    {
      "node-id": "D2",
```

```
"te-node-id": "2.0.1.2",
"te": {
  "te-node-attributes": {
    "domain-id": 1,
    "is-abstract": [
      null
    ],
    "connectivity-matrices": {
      "is-allowed": true,
      "underlay": {
        "enabled": true
      },
      "path-constraints": {
        "te-bandwidth": {
          "generic": "0x1p10"
        }
      },
      "optimizations": {
        "objective-function": {
          "objective-function-type": "of-maximize-residual-b
        }
      },
      "connectivity-matrix": [
        {
          "id": 105,
          "from": {
            "tp-ref": "1-0-1"
          },
          "to": {
            "tp-ref": "5-5-0"
          },
          "underlay": {
            "enabled": true,
            "primary-path": {
              "network-ref": "absolute",
              "path-element": [
                {
                  "path-element-id": 1,
                  "numbered-node-hop": {
                    "node-id": "4.4.4.4",
                    "hop-type": "strict"
                  }
                },
                {
                  "path-element-id": 2,
                  "numbered-hop": {
                    "node-id": "7.7.7.7",
                    "hop-type": "strict"
                  }
```

```
            }
          ]
        }
      }
    }
  ]
 }
},
"tunnel-termination-point": [
 {
  "name": "1-0-1",
  "tunnel-tp-id": 10001,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "1-1-0",
  "tunnel-tp-id": 10100,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "2-0-2",
  "tunnel-tp-id": 20002,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "2-2-0",
  "tunnel-tp-id": 20200,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "3-0-3",
  "tunnel-tp-id": 30003,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "3-3-0",
  "tunnel-tp-id": 30300,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
 },
 {
  "name": "4-0-4",
  "tunnel-tp-id": 40004,
  "switching-capability": "switching-otn",
```

```
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "4-4-0",
  "tunnel-tp-id": 40400,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-0-5",
  "tunnel-tp-id": 50005,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-5-0",
  "tunnel-tp-id": 50500,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "6-0-6",
  "tunnel-tp-id": 60006,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "6-6-0",
  "tunnel-tp-id": 60600,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "7-0-7",
  "tunnel-tp-id": 70007,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "7-7-0",
  "tunnel-tp-id": 70700,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "8-0-8",
  "tunnel-tp-id": 80008,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
```

```
          },
          {
            "name": "8-8-0",
            "tunnel-tp-id": 80800,
            "switching-capability": "switching-otn",
            "encoding": "lsp-encoding-oduk"
          }
        ]
      }
    }
  ]
},
{
  "network-types": {
    "te-topology": {}
  },
  "network-id": "abstract3",
  "te-topology-identifier": {
    "provider-id": 0,
    "client-id": 0,
    "topology-id": "abstract3"
  },
  "node": [
    {
      "node-id": "D3",
      "te-node-id": "3.0.1.1",
      "te": {
        "te-node-attributes": {
          "domain-id": 3,
          "is-abstract": [
            null
          ],
          "connectivity-matrices": {
            "is-allowed": true,
            "path-constraints": {
              "te-bandwidth": {
                "generic": "0x1p10"
              }
            },
            "connectivity-matrix": [
              {
                "id": 107,
                "from": {
                  "tp-ref": "1-0-1"
                },
                "to": {
                  "tp-ref": "7-7-0"
                }
              },
```

```
      {
        "id": 308,
        "from": {
          "tp-ref": "3-0-3"
        },
        "to": {
          "tp-ref": "8-8-0"
        }
      }
    ]
  }
},
"tunnel-termination-point": [
  {
    "name": "1-0-1",
    "tunnel-tp-id": 10001,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "1-1-0",
    "tunnel-tp-id": 10100,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "2-0-2",
    "tunnel-tp-id": 20002,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "2-2-0",
    "tunnel-tp-id": 20200,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "3-0-3",
    "tunnel-tp-id": 30003,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
  {
    "name": "3-3-0",
    "tunnel-tp-id": 30300,
    "switching-capability": "switching-otn",
    "encoding": "lsp-encoding-oduk"
  },
```

```
{
  "name": "4-0-4",
  "tunnel-tp-id": 40004,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "4-4-0",
  "tunnel-tp-id": 40400,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-0-5",
  "tunnel-tp-id": 50005,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "5-5-0",
  "tunnel-tp-id": 50500,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "6-0-6",
  "tunnel-tp-id": 60006,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "6-6-0",
  "tunnel-tp-id": 60600,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "7-0-7",
  "tunnel-tp-id": 70007,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
  "name": "7-7-0",
  "tunnel-tp-id": 70700,
  "switching-capability": "switching-otn",
  "encoding": "lsp-encoding-oduk"
},
{
```

```
                "name": "8-0-8",
                "tunnel-tp-id": 80008,
                "switching-capability": "switching-otn",
                "encoding": "lsp-encoding-oduk"
              },
              {
                "name": "8-8-0",
                "tunnel-tp-id": 80800,
                "switching-capability": "switching-otn",
                "encoding": "lsp-encoding-oduk"
              }
            ]
          }
        }
      ]
    }
  }
}
```

8. 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] 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 model presented in this document is used in the interface between the Customer Network Controller (CNC) and Multi-Domain Service Coordinator (MDSC), which is referred to as CNC-MDSC Interface (CMI). Therefore, many security risks such as malicious attack and rogue elements attempting to connect to various ACTN components. Furthermore, some ACTN components (e.g., MSDC) represent a single point of failure and threat vector and must also manage policy conflicts and eavesdropping of communication between different ACTN components.

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:

*ap:

-ap-id

-max-bandwidth

-avl-bandwidth

*vn-ap:

-vn-ap-id

-vn

-abstract-node

-ltp

```
     *vn

        -vn-id

        -vn-topology-id

        -abstract-node

     *vnm-id

        -src

        -src-vn-ap-id

        -dest

        -dest-vn-ap-id

        -connectivity-matrix-id
```

9. IANA Considerations

IANA is requested to make the following allocation for the URIs in the "ns" subregistry within the "IETF XML Registry" [RFC3688]:

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

IANA is requested to make the following allocation for the YANG module in the "YANG Module Names" registry [RFC6020]:

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

10. Acknowledgments

The authors would like to thank Xufeng Liu, Adrian Farrel, and Tom Petch for their helpful comments and valuable suggestions.

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Appendix A. Performance Constraints

At the time of creation of VN, it is natural to provide VN level constraints and optimization criteria. It should be noted that this YANG model rely on the TE-Topology Model [RFC8795] by using a reference to an abstract node to achieve this. Further, connectivity-matrix structure is used to assign the constraints and optimization criteria include delay, jitter etc. [RFC8776] define some of the metric-types already and future documents are meant to augment it.

Note that the VN compute allows inclusion of the constraints and the optimization criteria directly in the RPC to allow it to be used independently.

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