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SF Aware TE Topology YANG Model  
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Abstract

This document describes a YANG data model for TE network topologies that are network service and function aware.

Status of This Memo

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Table of Contents

- 1. Introduction . . . . . 3
  - 1.1. Terminology . . . . . 4
  - 1.2. Tree Diagrams . . . . . 5
  - 1.3. Prefixes in Data Node Names . . . . . 6
- 2. Modeling Considerations . . . . . 6
- 3. SF Aware TE Topology Model Structure . . . . . 7
- 4. SF Aware TE Topology YANG Module . . . . . 9
- 5. IANA Considerations . . . . . 19
- 6. Security Considerations . . . . . 20
- 7. References . . . . . 22
  - 7.1. Normative References . . . . . 22
  - 7.2. Informative References . . . . . 25
- Appendix A. Companion YANG Model for Non-NMDA Compliant Implementations . . . . . 26
  - A.1. SF Aware TE Topology State Module . . . . . 26
- Appendix B. Data Examples . . . . . 29
  - B.1. A Topology with Multiple Connected Network Functions . . . . . 29
  - B.2. A Topology with an Encapsulated Network Service . . . . . 34
- Appendix C. Use Cases for SF Aware Topology Models . . . . . 38
  - C.1. Exporting SF/NF Information to Network Clients and Other Network SDN Controllers . . . . . 38
  - C.2. Flat End-to-end SFCs Managed on Multi-domain Networks . . . . . 39
  - C.3. Managing SFCs with TE Constraints . . . . . 40
  - C.4. SFC Protection and Load Balancing . . . . . 41
  - C.5. Network Clock Synchronization . . . . . 44
  - C.6. Client - Provider Network Slicing Interface . . . . . 44
  - C.7. Dynamic Assignment of Regenerators for L0 Services . . . . . 44
  - C.8. Dynamic Assignment of OAM Functions for L1 Services . . . . . 46
  - C.9. SFC Abstraction and Scaling . . . . . 47
  - C.10. Dynamic Compute/VM/Storage Resource Assignment . . . . . 47
  - C.11. Application-aware Resource Operations and Management . . . . . 48

C.12. Interconnection between Service Functions/Termination  
 Points in uCPE . . . . . 49  
 Acknowledgements . . . . . 56  
 Authors' Addresses . . . . . 56

1. Introduction

RFC Ed.: In this document, please replace all occurrences of 'XXXX' with the actual RFC number (and remove this note).

Normally network connectivity services are discussed as a means to inter-connect various abstract or physical network topological elements, such as ports, link termination points and nodes [RFC8795] [I-D.ietf-teas-yang-te]. However, the connectivity services, strictly speaking, interconnect not the network topology elements per-se, rather, located on/associated with the various network and service functions [RFC7498] [RFC7665]. In many scenarios it is beneficial to decouple the service/network functions from the network topology elements hosting them, describe them in some unambiguous and identifiable way (so that it would be possible, for example, to auto-discover on the network topology service/network functions with identical or similar functionality and characteristics) and engineer the connectivity between the service/network functions, rather than between their current topological locations.

Today a network offers to its clients far more services than just connectivity across the network. Large variety of physical, logical and/or virtual service functions, network functions and transport functions (collectively named in this document as SFs) could be allocated for and assigned to a client. As described in the appendix of this document, there are some important use cases, in which the network needs to represent to the client SFs at the client's disposal as topological elements in relation to other elements of a topology (i.e. nodes, links, link and tunnel termination points) used by the network to describe itself to the client. Not only would such information allow for the client to auto-discover the network's SFs available for the services provisioned for the client, it would also allow for the client selecting the SFs, dual-optimizing the selection on the SF location on the network and connectivity means (e.g. TE tunnels) to inter-connect the SFs. Consequently thus would give to both the network and the client powerful means for the service function chain (SFC [RFC7498] [RFC7665]) negotiation to achieve most efficient and cost effective (from the network point of view) and most optimal yet satisfying all necessary constraints of SFCs (from the client's point of view).

This document defines a YANG [RFC7950] data model that allows service functions to be represented along with TE topology elements.

The YANG data model in this document conforms to the Network Management Datastore Architecture (NMDA) [RFC8342].

## 1.1. Terminology

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

- o Network Function (NF): A functional block within a network infrastructure that has well-defined external interfaces and well-defined functional behaviour [ETSI-NFV-TERM]. Such functions include message router, CDN, session border controller, WAN acceleration, DPI, firewall, NAT, QoE monitor, PE router, BRAS, and radio/fixed access network nodes.
- o Network Service: Composition of Network Function(s) and/or Network Service(s), defined by its functional and behavioural specification. The Network Service contributes to the behaviour of the higher layer service, which is characterized by at least performance, dependability, and security specifications. The end-to-end network service behaviour is the result of the combination of the individual network function behaviours as well as the behaviours of the network infrastructure composition mechanism [ETSI-NFV-TERM].
- o Service Function (SF): A function that is responsible for specific treatment of received packets. A service function can act at various layers of a protocol stack (e.g., at the network layer or other OSI layers). As a logical component, a service function can be realized as a virtual element or be embedded in a physical network element. One or more service functions can be embedded in the same network element. Multiple occurrences of the service function can exist in the same administrative domain. A non-exhaustive list of service functions includes: firewalls, WAN and application acceleration, Deep Packet Inspection (DPI), server load balancers, NAT44 [RFC3022], NAT64 [RFC6146], HTTP header enrichment functions, and TCP optimizers. The generic term "L4-L7 services" is often used to describe many service functions [RFC7498].
- o Service Function Chain (SFC): A service function chain defines an ordered or partially ordered set of abstract service functions and ordering constraints that must be applied to packets, frames, and/or flows selected as a result of classification. An example of an abstract service function is a firewall. The implied order may

not be a linear progression as the architecture allows for SFCs that copy to more than one branch, and also allows for cases where there is flexibility in the order in which service functions need to be applied. The term "service chain" is often used as shorthand for "service function chain" [RFC7498].

- o Connectivity Service: Any service between layer 0 and layer 3 aiming at delivering traffic among two or more end customer edge nodes connected to provider edge nodes. Examples include L3VPN, L2VPN etc.
- o Link Termination Point (LTP): A conceptual point of connection of a TE node to one of the TE links, terminated by the TE node. Cardinality between an LTP and the associated TE link is 1:0..1 [RFC8795].
- o Tunnel Termination Point (TTP): An element of TE topology representing one or several of potential transport service termination points (i.e. service client adaptation points such as WDM/Och transponder). TTP is associated with (hosted by) exactly one TE node. TTP is assigned with the TE node scope unique ID. Depending on the TE node's internal constraints, a given TTP hosted by the TE node could be accessed via one, several or all TE links terminated by the TE node [RFC8795].
- o Topology and Orchestration Specification for Cloud Applications (TOSCA): A language standard specified by OASIS, to describe service components and their relationships using a service topology, and management procedures using orchestration processes. OASIS is a nonprofit consortium that drives the development, convergence and adoption of open standards for the global information society.

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

- o augment
- o data model
- o data node

## 1.2. Tree Diagrams

A simplified graphical representation of the data model is presented in this document, by using the tree format defined in [RFC8340].

### 1.3. Prefixes in Data Node Names

In this document, names of data nodes, actions, and other data model objects are often used without a prefix, as long as it is clear from the context in which YANG module each name is defined. Otherwise, names are prefixed using the standard prefix associated with the corresponding YANG module, as shown in Table 1.

| Prefix   | YANG module           | Reference                    |
|----------|-----------------------|------------------------------|
| inet     | ietf-inet-types       | [RFC6991]                    |
| nw       | ietf-network          | [RFC8345]                    |
| nt       | ietf-network-topology | [RFC8345]                    |
| te-types | ietf-te-types         | [RFC8776]                    |
| tet      | ietf-te-topology      | [RFC8795]                    |
| actn-vn  | ietf-actn-vn          | [I-D.ietf-teas-actn-vn-yang] |

Table 1: Prefixes and Corresponding YANG Modules

## 2. Modeling Considerations

The model introduced in this document is an augmentation of the TE Topology model defined in [RFC8795]. SFs are modeled as child elements of a TE node similarly to how Link Termination Points (LTPs) and Tunnel Termination Points (TTPs) are modeled in the TE Topology model. The SFs are defined as opaque objects identified via topology unique service-function-id's. Each SF has one or more Connection Points (CPs) identified via SF-unique sf-connection-point-id's, over which the SF could be connected to other SFs resided on the same TE node, as well as to other elements of the TE node, in particular, to the node's LTPs and/or TTPs. An interested client may use service-function-id's to look up the SFs in TOSCA or YANG data store(s) defined by [ETSI-NFV-YANG] to retrieve the details of the SFs, for example, to understand the SF's mutual substitutability.

The TE Topology model introduces a concept of Connectivity Matrix (CM), and uses the CM to describe which and at what costs a TE node's LTPs could be inter-connected internally across the TE node. The model defined in this document heavily uses the same concept to describe the SF connectivity via introducing 3 additional CMs:

1. SF2SF CM (SF to SF Connectivity Matrix). This CM describes which pairs of SFs could be locally inter-connected, and, if yes, in which direction, via which CPs and at what costs. In other words, the SF2SF CM describes how SFs residing on the same TE

node could be inter-connected into local from the TE node's perspective SFCs;

2. SF2LTP CM (SF to LTP Connectivity Matrix). This CM describes how, in which direction and at what costs the TE node's SFs could be connected to the TE node's LTPs and hence to SFs residing on neighboring TE nodes that are connected to LTPs at the remote ends of corresponding TE links;
3. SF2TTP CM (SF to TTP Connectivity Matrix). This CM describes how, in which direction and at what costs the TE node's SFs could be connected to the TE node's TTPs and hence to SFs residing on other TE nodes on the topology that could be inter-connected with the TE node in question via TE tunnels terminated by the corresponding TTPs.

In addition to SF2SF CM, the local SF chaining could be described with the help of ETSI models Virtual Links (VLs) [ETSI-NFV-YANG]. This option is especially useful when the costs of the local chaining are negligible as compared to ones of the end-to-end SFCs said local SFCs are part of.

Section 3 and 4 provide the YANG model structure and the YANG module for SF-aware Topology. Section 5 and 6 provide the YANG model structure and the YANG module for Data Center Compute Node resource abstraction. This provides an example of SF2LTP CM where DC compute nodes are connected to LTPs at the remote ends of the corresponding TE links. This use-case is described in Section 10 of Appendix C.

### 3. SF Aware TE Topology Model Structure

```

module: ietf-te-topology-sf
  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw sf!
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes:
      +--rw service-function
        +--rw connectivity-matrices
          | +--rw connectivity-matrix* [id]
          |   +--rw id                uint32
          |   +--rw from
          |     | +--rw service-function-id?    leafref
          |     | +--rw sf-connection-point-id? leafref
          |     +--rw to
          |       | +--rw service-function-id?    leafref
          |       | +--rw sf-connection-point-id? leafref
          |       +--rw enabled?                boolean

```

```

    |      +--rw direction?          connectivity-direction
    |      +--rw virtual-link-id?   string
+--rw link-terminations
    +--rw link-termination* [id]
        +--rw id                    uint32
        +--rw from
            | +--rw tp-ref?         leafref
        +--rw to
            | +--rw service-function-id?    leafref
            | +--rw sf-connection-point-id? leafref
        +--rw enabled?              boolean
        +--rw direction?           connectivity-direction
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry:
+--ro service-function
    +--ro connectivity-matrices
    | +--ro connectivity-matrix* [id]
    | +--ro id                    uint32
    | +--ro from
    | | +--ro service-function-id?    leafref
    | | +--ro sf-connection-point-id? leafref
    | +--ro to
    | | +--ro service-function-id?    leafref
    | | +--ro sf-connection-point-id? leafref
    | +--ro enabled?              boolean
    | +--ro direction?           connectivity-direction
    | +--ro virtual-link-id?     string
+--ro link-terminations
    +--ro link-termination* [id]
        +--ro id                    uint32
        +--ro from
            | +--ro tp-ref?         leafref
        +--ro to
            | +--ro service-function-id?    leafref
            | +--ro sf-connection-point-id? leafref
        +--ro enabled?              boolean
        +--ro direction?           connectivity-direction
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point:
+--rw service-function
    +--rw tunnel-terminations
        +--rw tunnel-termination* [id]
            +--rw id                    uint32
            +--rw service-function-id?    leafref
            +--rw sf-connection-point-id? leafref
            +--rw enabled?              boolean
            +--rw direction?           connectivity-direction
augment /nw:networks/nw:network/nw:node:

```



```
+--rw service-functions
  +--rw service-function* [id]
    +--rw id                string
    +--rw type?             identityref
    +--rw te-metric?        te-types:te-metric
    +--rw priority?         uint8
    +--rw connection-points
      +--rw connection-point* [id]
        +--rw id            string
        +--rw type?         identityref
```

#### 4. SF Aware TE Topology YANG Module

This module references [RFC7665], [RFC8345], [RFC8776], [RFC8795], [ETSI-NFV-YANG], and [ETSI-NFV-PACKAGE].

```
<CODE BEGINS> file "ietf-te-topology-sf@2022-02-25.yang"
module ietf-te-topology-sf {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-te-topology-sf";

  prefix "tet-sf";

  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-te-types {
    prefix "te-types";
    reference
      "RFC8776: Common YANG Data Types for Traffic Engineering.";
```

```
}

organization
  "Traffic Engineering Architecture and Signaling (TEAS)
  Working Group";

contact
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  WG List: <mailto:teas@ietf.org>

  Editors: Igor Bryskin
           <mailto:Igor.Bryskin@huawei.com>

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

description
  "Network service and function aware TE topology model.

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

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

revision 2022-02-25 {
  description "Initial revision";
  reference "RFC XXXX: SF Aware TE Topology YANG Model";
}

/*
 * Identities
 */
identity sf-type {
  description
    "Base identity from which all service function types are
    derived. The definitions of the derived identities are
    left to the implementation. An example can be 'firewall.'";
}
identity cp-type {
  description
```

```
    "Base identity from which all connection point types are
    derived. The definitions of the derived identities are
    left to the implementation. Examples can be 'ethernet',
    'mpls', or 'ipv4'. ";
  }

/*
 * Typedefs
 */
typedef connectivity-direction {
  type enumeration {
    enum "to" {
      description
        "The direction is uni-directional, towards the 'to'
        entity direction.";
    }
    enum "from" {
      description
        "The direction is uni-directional, from the 'to'
        entity direction.";
    }
    enum "bidir" {
      description
        "The direction is bi-directional.";
    }
  }
  description
    "A type used to indicates whether a connectivity is
    uni-directional, or bi-directional. If the relation is
    uni-directional, the value of this type indicates the
    direction.";
} // connectivity-direction

/*
 * Groupings
 */
grouping service-function-connection-point-ref {
  description
    "Reference to a service function connection point.";
  leaf service-function-id {
    type leafref {
      path "../..../..../..../..../service-functions/"
        + "service-function/id";
    }
    description
      "Reference to a service function id.";
  }
  leaf sf-connection-point-id {
```

```

    type leafref {
      path "../..../..../..../..../service-functions/"
        + "service-function[id=current()../service-function-id]/"
        + "connection-points/connection-point/id";
    }
    description
      "Reference to a SF(service function) connection point id.";
  }
} // service-function-connection-point-ref

grouping service-function-node-augmentation {
  description
    "Augmenting a node to contain a list of available service
    functions.";
  container service-functions {
    description
      "Containing the service functions that are available on this
      node. Any of these service functions can be referenced
      and enabled in te-node-attributes";
    list service-function {
      key "id";
      description
        "A list of service functions on this node.";
      leaf id {
        type string;
        description "Identifies the service function.";
      }
      leaf type {
        type identityref {
          base "sf-type";
        }
        description
          "The service function type, such as 'firewall'.
          The parameters of each service function type are not
          specified in this model, and may be specified by other
          models such as the one defined by ETSI GS NFV-IFA 011.";
        reference
          "ETSI-NFV-PACKAGE: ETSI GS NFV-IFA 011:
          Network Functions Virtualisation (NFV) Release 4;
          Management and Orchestration;
          VNF Descriptor and Packaging Specification.";
      }
    }
    leaf te-metric {
      type te-types:te-metric;
      description
        "Specifies the TE (Traffic Engineering) metric for this
        service function. The server uses this value as a
        preference of selecting the given service function

```

```
        instance.";
    }
    leaf priority {
        type uint8;
        default 0;
        description
            "Specifies the priority level at which the service
            function instance is available.
            A lower number indicates a higher priority.  The highest
            priority is 0.";
    }
    container connection-points {
        description
            "Containing the connection points that are available on
            this service function.
            node. Any of these connection points can be referenced
            and enabled in te-node-attributes";
        list connection-point {
            key "id";
            description
                "A list of connection points on this node.";
            leaf id {
                type string;
                description "Identifies the connection point.";
            }
            leaf type {
                type identityref {
                    base "cp-type";
                }
                description
                    "The connection point type, such as 'ethernet',
                    'mpls', or 'ipv4'.
                    The parameters of each service function type are not
                    specified in this model, and may be specified by
                    other models such as the one defined by ETSI GS
                    NFV-IFA 011.";
                reference
                    "ETSI-NFV-PACKAGE: ETSI GS NFV-IFA 011:
                    Network Functions Virtualisation (NFV) Release 4;
                    Management and Orchestration;
                    VNF Descriptor and Packaging Specification.";
            }
        }
    }
}
}
}
} // service-function-node-augmentation
```

```
grouping service-function-node-te-augmentation {
  description
    "Augmenting a TE node to be network service and function
    aware.";
  container service-function {
    description
      "Containing attributes related to network services and
      network functions";
    container connectivity-matrices {
      description
        "Connectivity relations between network services/functions
        on a TE node, which can be either abstract or physical.";
      reference
        "ETSI-NFV-YANG: ETSI GS NFV-SOL 006:
        Network Functions Virtualisation (NFV) Release 3;
        Protocols and Data Models;
        NFV descriptors based on YANG specification.
        RFC7665: Service Function Chaining (SFC) Architecture.";
      list connectivity-matrix {
        key "id";
        description
          "Represents the connectivity relations between network
          services/functions on a TE node.";
        leaf id {
          type uint32;
          description "Identifies the connectivity-matrix entry.";
        }

        container from {
          description
            "Reference to the source network service or
            network function.";
          uses service-function-connection-point-ref;
        } // from
        container to {
          description
            "Reference to the destination network service or
            network function.";
          uses service-function-connection-point-ref;
        } // to
        leaf enabled {
          type boolean;
          description
            "'true' if this connectivity entry is enabled.";
        }
        leaf direction {
          type connectivity-direction;
          description

```

```
        "Indicates whether this connectivity is
        uni-directional, or bi-directional. If the
        relation is uni-directional, the value of
        this leaf indicates the direction.";
    }
    leaf virtual-link-id {
        type string;
        description
            "Reference to a virtual link that models this
            connectivity relation in the network function
            model.";
    }
} // connectivity-matrix
} // connectivity-matrices

container link-terminations {
    description
        "Connectivity relations between network services/functions
        and link termination points on a TE node, which can be
        either abstract or physical.";
    reference
        "ETSI-NFV-YANG: ETSI GS NFV-SOL 006:
        Network Functions Virtualisation (NFV) Release 3;
        Protocols and Data Models;
        NFV descriptors based on YANG specification.
        RFC7665: Service Function Chaining (SFC) Architecture.";
    list link-termination {
        key "id";
        description
            "Each entry of the list represents the connectivity
            relation between a network service/function and
            a link termination point on a TE node.";
        leaf id {
            type uint32;
            description "Identifies the termination entry.";
        }

        container from {
            description
                "Reference to the link termination point.";
        } // from
        container to {
            description
                "Reference to the network service or network
                function.";
            uses service-function-connection-point-ref;
        } // to
        leaf enabled {
```

```

        type boolean;
        description
            "'true' if this connectivity entry is enabled.";
    }
    leaf direction {
        type connectivity-direction;
        description
            "Indicates whether this connectivity is
            uni-directional, or bi-directional. If the
            relation is uni-directional, the value of
            this leaf indicates the direction.";
    }
} // link-termination
}
} // service-function-node-te-augmentation

grouping service-function-ttp-augmentation {
    description
        "Augmenting a tunnel termination point to be network service
        aware.";
    container service-function {
        description
            "Containing attributes related to network services and
            network functions";
        container tunnel-terminations {
            description
                "Connectivity relations between network services/functions
                and tunnel termination points on a TE node, which can be
                either abstract or physical.";
            reference
                "ETSI-NFV-YANG: ETSI GS NFV-SOL 006:
                Network Functions Virtualisation (NFV) Release 3;
                Protocols and Data Models;
                NFV descriptors based on YANG specification.
                RFC7665: Service Function Chaining (SFC) Architecture.";
            list tunnel-termination {
                key "id";
                description
                    "Each entry of the list represents the connectivity
                    relation between a network service/function and
                    a tunnel termination point on a TE node.";
                leaf id {
                    type uint32;
                    description "Identifies the termination entry.";
                }
                leaf service-function-id {
                    type leafref {

```



```

        path "../..../..../..../..../service-functions/"
          + "service-function/id";
      }
      description
        "Reference to a service function id.";
    }
    leaf sf-connection-point-id {
      type leafref {
        path "../..../..../..../..../service-functions/"
          + "service-function[id=current()]/../"
          + "service-function-id]/connection-points/"
          + "connection-point/id";
      }
      description
        "Reference to a SF(service function) connection point
        id.";
    }
    leaf enabled {
      type boolean;
      description
        "'true' if this connectivity entry is enabled.";
    }
    leaf direction {
      type connectivity-direction;
      description
        "Indicates whether this connectivity is
        uni-directional, or bi-directional. If the
        relation is uni-directional, the value of
        this leaf indicates the direction.";
    }
  } // link-termination
}
} // service-function-ttp-augmentation

grouping sf-topology-type {
  description
    "Identifies the SF aware TE topology type.";
  container sf {
    presence "Indicates that the TE topology is SF aware.";
    description
      "Its presence identifies that the TE topology is SF aware.";
  }
} // sf-topology-type

grouping termination-point-ref {
  description
    "Reference to a link termination point.";
}

```

```
leaf tp-ref {
  type leafref {
    path "../../../../../nt:termination-point/"
      + "nt:tp-id";
  }
  description
    "Reference to the link termination point.";
}
} // termination-point-ref

/*
 * Augmentations
 */
/* Augmentations to network-types/te-topology */
augment "/nw:networks/nw:network/nw:network-types/"
  + "tet:te-topology" {
  description
    "Defines the SF aware TE topology type.";
  uses sf-topology-type;
}

/* Augmentations to te-node-attributes */
augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes" {
  description
    "Parameters for SF aware TE topology.";
  uses service-function-node-te-augmentation;
}

/* Augmentations to information-source-entry */
augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry" {
  description
    "Parameters for SF aware TE topology.";
  uses service-function-node-te-augmentation;
}

/* Augmentations to tunnel-termination-point */
augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point" {
  description
    "Parameters for SF aware TE topology.";
  uses service-function-ttp-augmentation;
}

/* Augmentations to link-termination under te-node-attributes */
augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet-sf:service-function/"
```

```

+ "tet-sf:link-terminations/tet-sf:link-termination/"
+ "tet-sf:from" {
description
  "Add reference to the link termination point.";
uses termination-point-ref;
}

/* Augmentations to link-termination under
   information-source-entry */
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet-sf:service-function/"
+ "tet-sf:link-terminations/tet-sf:link-termination/"
+ "tet-sf:from" {
description
  "Add reference to the link termination point.";
uses termination-point-ref;
}

/* Augmentations to node */
augment "/nw:networks/nw:network/nw:node" {
description
  "Available service functions on the node.";
uses service-function-node-augmentation;
}
}
<CODE ENDS>

```

## 5. IANA Considerations

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

```

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

```

```

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

```

This document registers the following YANG modules in the YANG Module Names registry [RFC6020]:

```

-----
name:          ietf-te-topology-sf
namespace:    urn:ietf:params:xml:ns:yang:ietf-te-topology-packet
prefix:       tet-sf
reference:    RFC XXXX
-----

```

```

-----
name:          ietf-te-topology-sf-state
namespace:    urn:ietf:params:xml:ns:yang:ietf-te-topology-packet-state
prefix:       tet-sf-s
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 Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

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

```

/nw:networks/nw:network/nw:network-types/tet:te-topology/sf
  This subtree specifies the topology type. Modifying the
  configurations can make topology type invalid and cause
  interruption to the specified SF Aware TE topology and the related
  SF Aware TE topologies.

```

```

/nw:networks/nw:network/nw:node/tet:te/tet:te-node-attributes/
service-function
  This subtree specifies the configurations of service functions in
  SF Aware TE nodes. Modifying the configurations in this subtree
  can change the configurations of service functions in the

```

specified node, causing these service functions disabled or misbehaving in the specified node.

/nw:networks/nw:network/nw:node/tet:te/tet:tunnel-termination-point/service-function

This subtree specifies the configurations of service functions on a tunnel-termination-point in SF Aware TE nodes. Modifying the configurations in this subtree can change the configurations of service functions on the specified tunnel-termination-point in the specified node, causing these service functions disabled or misbehaving.

/nw:networks/nw:network/nw:node/service-functions

This subtree specifies the available service functions in SF Aware TE nodes. Modifying the configurations in this subtree can change the configurations of the available service functions in the specified node, causing these service functions disabled or misbehaving in the specified node.

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:

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

Unauthorized access to this subtree can disclose the SF Aware TE topology type.

/nw:networks/nw:network/nw:node/tet:te/tet:te-node-attributes/service-function

Unauthorized access to this subtree can disclose the operational state information of the service functions in the specified SF Aware TE node.

/nw:networks/nw:network/nw:node/tet:te/tet:information-source-entry/service-function

Unauthorized access to this subtree can disclose the operational state information of the service functions in the specified SF Aware TE node.

/nw:networks/nw:network/nw:node/tet:te/tet:tunnel-termination-point/service-function

Unauthorized access to this subtree can disclose the operational state information of the service functions on the specified tunnel-termination-point in the specified SF Aware TE node.

/nw:networks/nw:network/nw:node/service-functions

Unauthorized access to this subtree can disclose the operational state information of the available service functions in the specified node.

## 7. References

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## Appendix A. Companion YANG Model for Non-NMDA Compliant Implementations

The YANG module `ietf-te-topology-sf` defined in this document is designed to be used in conjunction with implementations that support the Network Management Datastore Architecture (NMDA) defined in [RFC8342]. In order to allow implementations to use the model even in cases when NMDA is not supported, the following companion module, `ietf-te-topology-sf-state`, is defined as state model, which mirrors the module `ietf-te-topology-sf` defined earlier in this document. However, all data nodes in the companion module are non-configurable, to represent the applied configuration or the derived operational states.

The companion module, `ietf-te-topology-sf-state`, is redundant and SHOULD NOT be supported by implementations that support NMDA.

As the structure of the companion module mirrors that of the cooresponding NMDA model, the YANG tree of the companion module is not depicted separately.

## A.1. SF Aware TE Topology State Module

```
<CODE BEGINS> file "ietf-te-topology-sf-state@2022-02-25.yang"
module ietf-te-topology-sf-state {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-te-topology-sf-state";

  prefix "tet-sf-s";

  import ietf-te-topology-sf {
    prefix "tet-sf";
    reference
      "RFC XXXX: SF Aware TE Topology YANG Model";
  }

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

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

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

organization
  "Traffic Engineering Architecture and Signaling (TEAS)
  Working Group";

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

  Editors: Igor Bryskin
           <mailto:Igor.Bryskin@huawei.com>

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

description
  "Network service and function aware aware TE topology operational
  state model for non-NMDA compliant implementations.

  Copyright (c) 2021 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 2022-02-25 {
  description "Initial revision";
  reference "RFC XXXX: SF Aware TE Topology YANG Model";
}

/*
 * Groupings
 */
grouping state-termination-point-ref {
  description
```

```
    "Reference to a link termination point in this non-NMDA state
    module.";
  leaf tp-ref {
    type leafref {
      path "../..//../..//../..//../..//nt-s:termination-point/"
        + "nt-s:tp-id";
    }
    description
      "Reference to the link termination point.";
  }
} // termination-point-ref

/*
 * Augmentations
 */
/* Augmentations to network-types/te-topology */
augment "/nw-s:networks/nw-s:network/nw-s:network-types/"
  + "tet-s:te-topology" {
  description
    "Defines the SF aware TE topology type.";
  uses tet-sf:sf-topology-type;
}

/* Augmentations to te-node-attributes */
augment "/nw-s:networks/nw-s:network/nw-s:node/tet-s:te/"
  + "tet-s:te-node-attributes" {
  description
    "Parameters for SF aware TE topology.";
  uses tet-sf:service-function-node-te-augmentation;
}

/* Augmentations to information-source-entry */
augment "/nw-s:networks/nw-s:network/nw-s:node/tet-s:te/"
  + "tet-s:information-source-entry" {
  description
    "Parameters for SF aware TE topology.";
  uses tet-sf:service-function-node-te-augmentation;
}

/* Augmentations to tunnel-termination-point */
augment "/nw-s:networks/nw-s:network/nw-s:node/tet-s:te/"
  + "tet-s:tunnel-termination-point" {
  description
    "Parameters for SF aware TE topology.";
  uses tet-sf:service-function-ttp-augmentation;
}

/* Augmentations to link-termination under te-node-attributes */
```

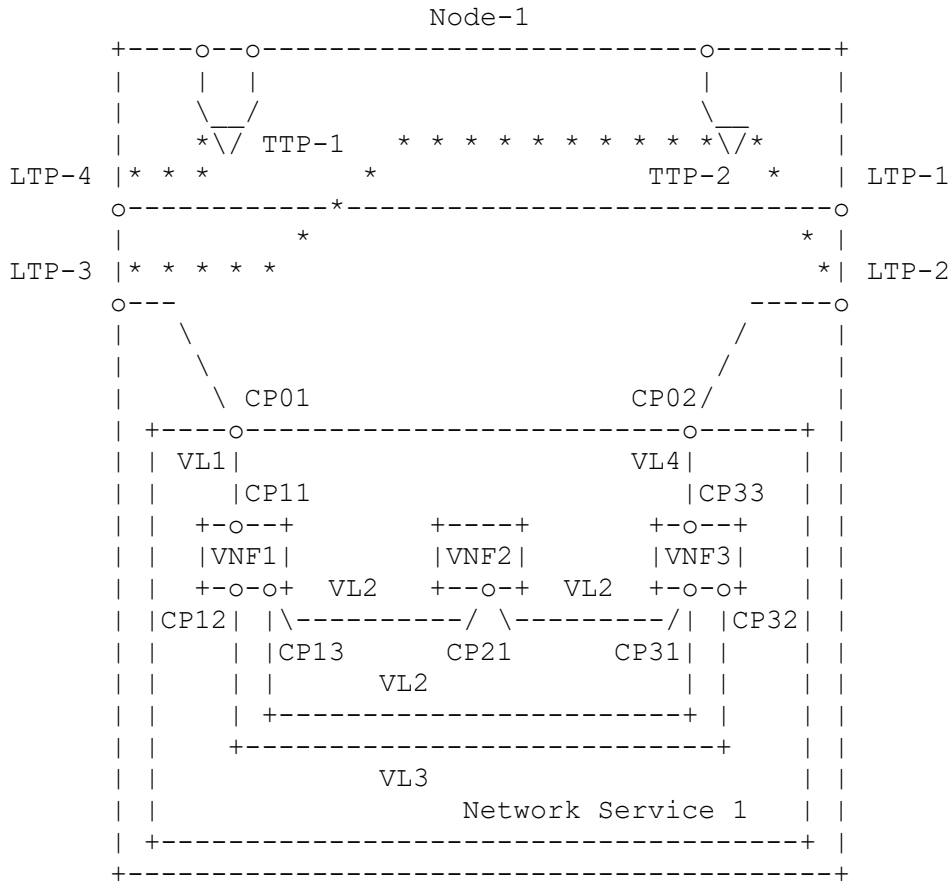
```
augment "/nw-s:networks/nw-s:network/nw-s:node/tet-s:te/"
  + "tet-s:te-node-attributes/tet-sf-s:service-function/"
  + "tet-sf-s:link-terminations/tet-sf-s:link-termination/"
  + "tet-sf-s:from" {
  description
    "Add reference to the link termination point.";
  uses state-termination-point-ref;
}

/* Augmentations to link-termination under
   information-source-entry */
augment "/nw-s:networks/nw-s:network/nw-s:node/tet-s:te/"
  + "tet-s:information-source-entry/tet-sf-s:service-function/"
  + "tet-sf-s:link-terminations/tet-sf-s:link-termination/"
  + "tet-sf-s:from" {
  description
    "Add reference to the link termination point.";
  uses state-termination-point-ref;
}

/* Augmentations to node */
augment "/nw-s:networks/nw-s:network/nw-s:node" {
  description
    "Available service functions on the node.";
  uses tet-sf:service-function-node-augmentation;
}
}
<CODE ENDS>
```

## Appendix B. Data Examples

### B.1. A Topology with Multiple Connected Network Functions



The configuration instance data for Node-1 in the above figure could be as follows:

```

{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {
            "sf": {}
          }
        },
        "network-id": "network-sf-aware",
        "provider-id": 201,
        "client-id": 300,
        "te-topology-id": "te-topology:network-sf-aware",
        "node": [
          {
            "node-id": "Node-1",

```

```

"te-node-id": "2.0.1.1",
"te": {
  "te-node-attributes": {
    "domain-id": 1,
    "is-abstract": [null],
    "connectivity-matrices": {
    },
    "service-function": {
      "connectivity-matrices": {
        "connectivity-matrix": [
          {
            "id": 10,
            "from": {
              "service-function-id": "Network Service 1",
              "sf-connection-point-id": "CP01"
            },
            "to": {
              "service-function-id": "VNF1",
              "sf-connection-point-id": "CP11"
            }
          },
          {
            "id": 13,
            "from": {
              "service-function-id": "VNF1",
              "sf-connection-point-id": "CP12"
            },
            "to": {
              "service-function-id": "VNF3",
              "sf-connection-point-id": "CP32"
            }
          },
          {
            "id": 12,
            "from": {
              "service-function-id": "VNF1",
              "sf-connection-point-id": "CP13"
            },
            "to": {
              "service-function-id": "VNF2",
              "sf-connection-point-id": "CP21"
            }
          }
        ],
        "direction": "bidir",
        "virtual-link-id": "VL1"
      },
      "direction": "bidir",
      "virtual-link-id": "VL3"
    },
    "direction": "bidir",
    "virtual-link-id": "VL2"
  }
}

```

```
    },
    {
      "id": 23,
      "from": {
        "service-function-id": "VNF2",
        "sf-connection-point-id": "CP21"
      },
      "to": {
        "service-function-id": "VNF3",
        "sf-connection-point-id": "CP31"
      }
      "direction": "bidir",
      "virtual-link-id": "VL2"
    },
    {
      "id": 30,
      "from": {
        "service-function-id": "Network Service 1",
        "sf-connection-point-id": "CP02"
      },
      "to": {
        "service-function-id": "VNF3",
        "sf-connection-point-id": "CP33"
      }
      "direction": "bidir",
      "virtual-link-id": "VL4"
    }
  ]
},
"link-terminations": {
  "link-termination": [
    {
      "id": 2,
      "from": {
        "tp-ref": "LTP-2"
      },
      "to": {
        "service-function-id": "Network Service 1",
        "sf-connection-point-id": "CP02"
      }
      "direction": "bidir"
    },
    {
      "id": 3,
      "from": {
        "tp-ref": "LTP-3"
      },
      "to": {
```





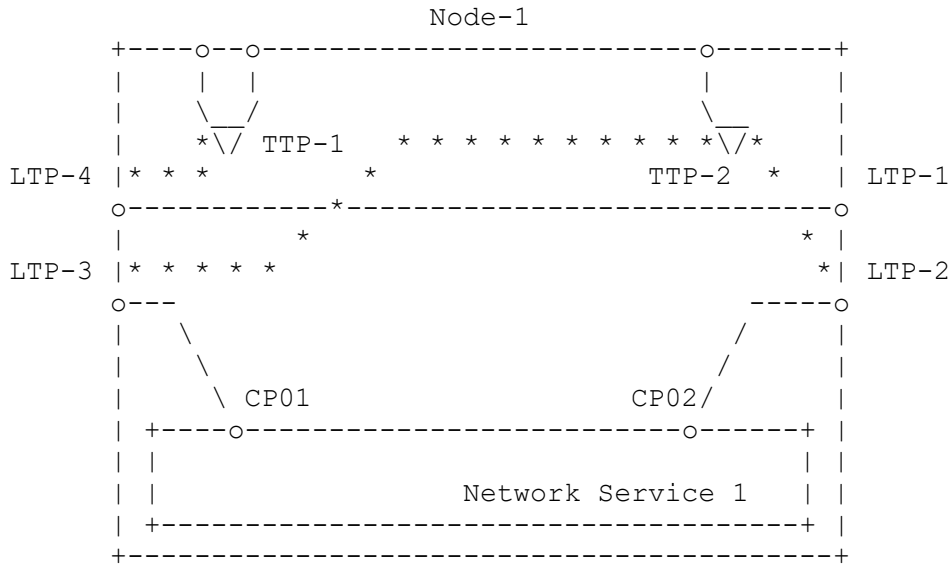
```

    },
    {
      "tp-id": "LTP-3",
      "te-tp-id": 10003
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-l2sc",
            "encoding": "lsp-encoding-ethernet"
          }
        ]
      }
    },
    {
      "tp-id": "LTP-4",
      "te-tp-id": 10004
      "te": {
        "interface-switching-capability": [
          {
            "switching-capability": "switching-l2sc",
            "encoding": "lsp-encoding-ethernet"
          }
        ]
      }
    }
  ]
}

```

## B.2. A Topology with an Encapsulated Network Service

In this example, a network service consists of several interconnected network functions (NFs), and is represented by this model as an encapsulated opaque object without the details between its internals.



The configuration instance data for Node-1 in the above figure could be as follows:

```

{
  "networks": {
    "network": [
      {
        "network-types": {
          "te-topology": {
            "sf": {}
          }
        },
        "network-id": "network-sf-aware",
        "provider-id": 201,
        "client-id": 300,
        "te-topology-id": "te-topology:network-sf-aware",
        "node": [
          {
            "node-id": "Node-1",
            "te-node-id": "2.0.1.1",
            "te": {
              "te-node-attributes": {
                "domain-id": 1,
                "is-abstract": [null],
                "connectivity-matrices": {
                },
              },
              "service-function": {
                "connectivity-matrices": {
                },
              },
            },
          }
        ]
      }
    ]
  }
}

```



```

    "interface-switching-capability": [
      {
        "switching-capability": "switching-l2sc",
        "encoding": "lsp-encoding-ethernet"
      }
    ]
  },
  {
    "tp-id": "LTP-2",
    "te-tp-id": 10002
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-l2sc",
          "encoding": "lsp-encoding-ethernet"
        }
      ]
    }
  },
  {
    "tp-id": "LTP-3",
    "te-tp-id": 10003
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-l2sc",
          "encoding": "lsp-encoding-ethernet"
        }
      ]
    }
  },
  {
    "tp-id": "LTP-4",
    "te-tp-id": 10004
    "te": {
      "interface-switching-capability": [
        {
          "switching-capability": "switching-l2sc",
          "encoding": "lsp-encoding-ethernet"
        }
      ]
    }
  }
]
}

```

```
    ]  
  }  
}
```

## Appendix C. Use Cases for SF Aware Topology Models

### C.1. Exporting SF/NF Information to Network Clients and Other Network SDN Controllers

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

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

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

The issue of exporting of SF/NF information could be addressed by defining a model, in which formally described/recognizable SF/NF instances are presented as topological elements, for example, hosted by TE, L3 or L2 topology nodes (see Figure 1). The model could describe whether, how and at what costs the SFs/NFs hosted by a given node could be chained together, how these intra-node SFCs could be connected to the node's Service Function Forwarders (SFFs, entities dealing with SFC NSHs and metadata), and how the SFFs could be connected to the node's Tunnel and Link Termination Points (TTPs and LTPs) to chain the intra-node SFCs across the network topology.

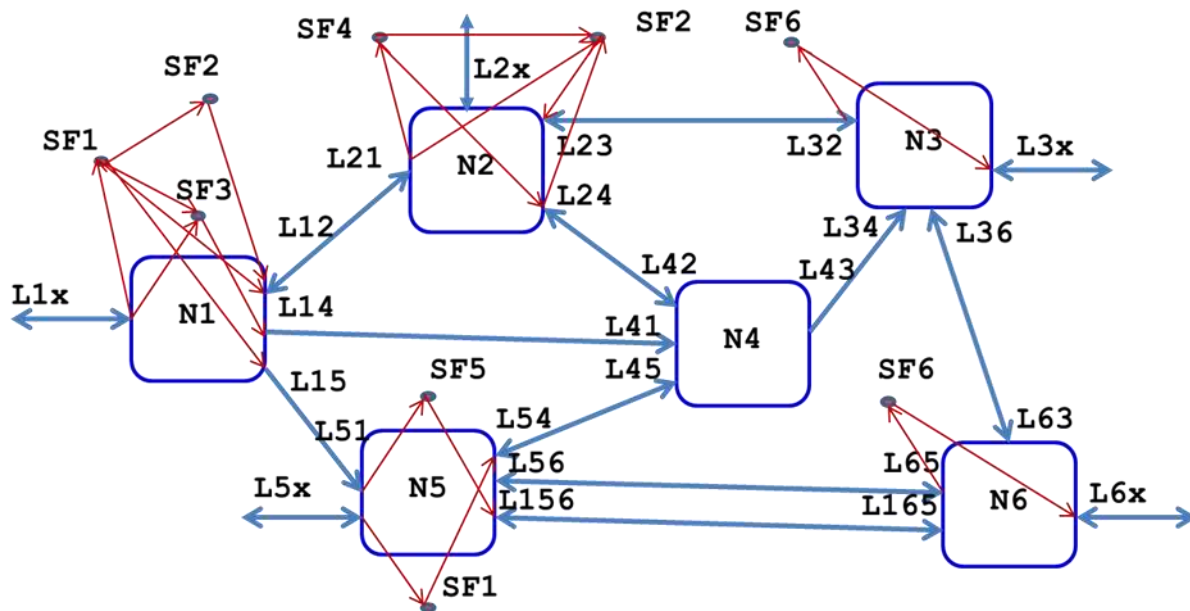


Figure 1: SF/NF aware TE topology

### C.2. Flat End-to-end SFCs Managed on Multi-domain Networks

SFCs may span multiple administrative domains, each of which controlled by a separate SFC controller. The usual solution for such a scenario is the Hierarchical SFCs (H-SFCs) [RFC8459], in which the higher level orchestrator controls only SFs located on domain border nodes. Said higher level SFs are chained together into higher level SFCs via lower level (intra-domain) SFCs provisioned and controlled independently by respective domain controllers. The decision as to which higher level SFCs are connected to which lower level SFCs is driven by packet re-classification every time the packet enters a given domain. Said packet re-classification is a very time-consuming operation. Furthermore, the independent nature of higher and lower level SFC control is prone to configuration errors, which may lead to long lasting loops and congestions. It is highly desirable to be able to set up and manage SFCs spanning multiple domains in a flat way as far as the data plane is concerned (i.e. with a single packet classification at the ingress into the multi-domain network but without re-classifications on domain ingress nodes).

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

connectivity (TE tunnels) on a multi-domain multi-vendor transport network.

### C.3. Managing SFCs with TE Constraints

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

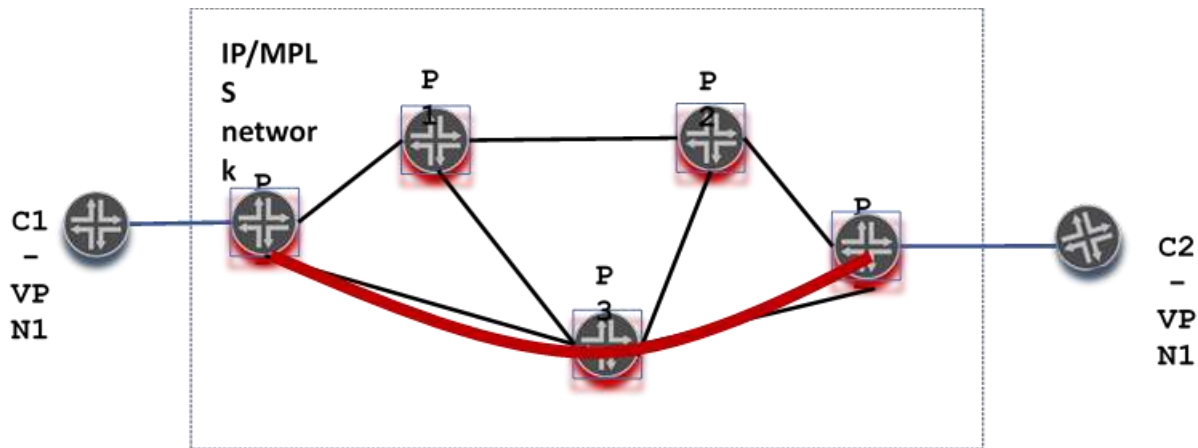


Figure 2: L3 VPN with delay constraints

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

SF/NF-aware TE topology model in combination with TE tunnel model will allow for the network orchestrator (or a client controller) to compute, set up and manipulate the TE overlays in the form of TE tunnel chains (see Figure 3).



Said chains could be dual-optimized compromising on optimal SF/NF locations with optimal TE tunnels interconnecting them. The TE tunnel chains (carrying multiple similarly constrained SFPs) could be adequately constrained both at individual TE tunnel level and at the chain end-to-end level.

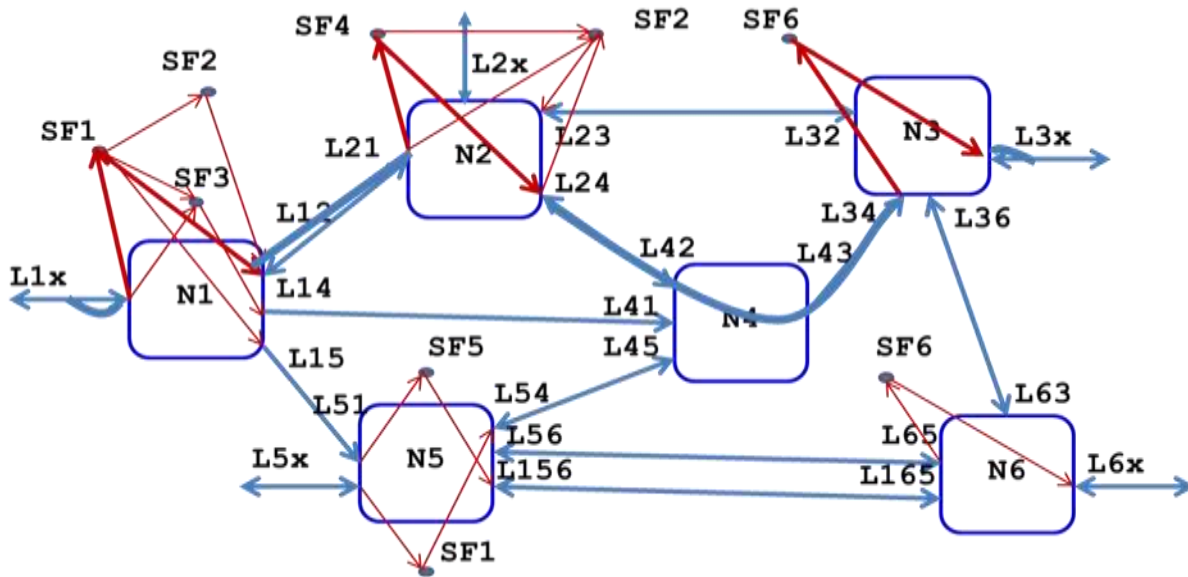


Figure 3: SFC with TE constraints

#### C.4. SFC Protection and Load Balancing

Currently the combination of TE topology & tunnel models offers to a network controller various capabilities to recover an individual TE tunnel from network failures occurred on one or more network links or transit nodes on the TE paths taken by the TE tunnel's connection(s). However, there is no simple way to recover a TE tunnel from a failure affecting its source or destination node. SF/NF-aware TE topology model can decouple the association of a given SF/NF with its location on the network topology by presenting multiple, identifiable as mutually substitutable SFs/NFs hosted by different TE topology nodes. So, for example, if it is detected that a given TE tunnel destination node is malfunctioning or has gone out of service, the TE tunnel could be re-routed to terminate on a different node hosting functionally the same SFs/NFs as ones hosted by the failed node (see Figures 6).

This is in line with the ACTN edge migration and function mobility concepts [RFC8453]. It is important to note that the described strategy works much better for the stateless SFs/NFs. This is because getting the alternative stateful SFs/NFs into the same respective states as the current (i.e. active, affected by failure) are is a very difficult challenge.

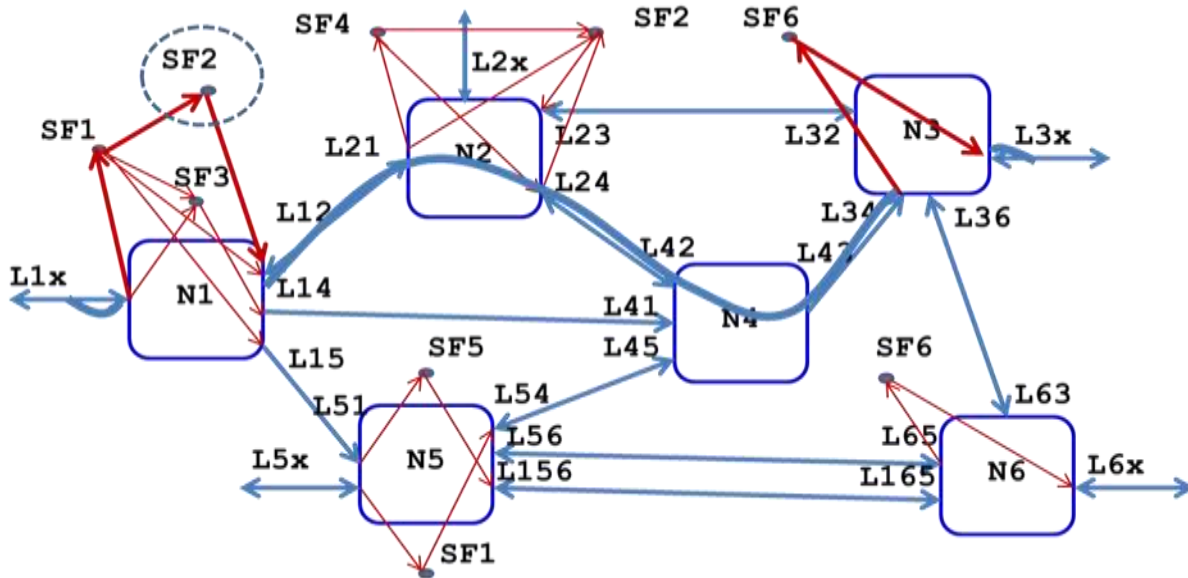


Figure 4: SFC recovery: SF2 on node NE1 fails

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

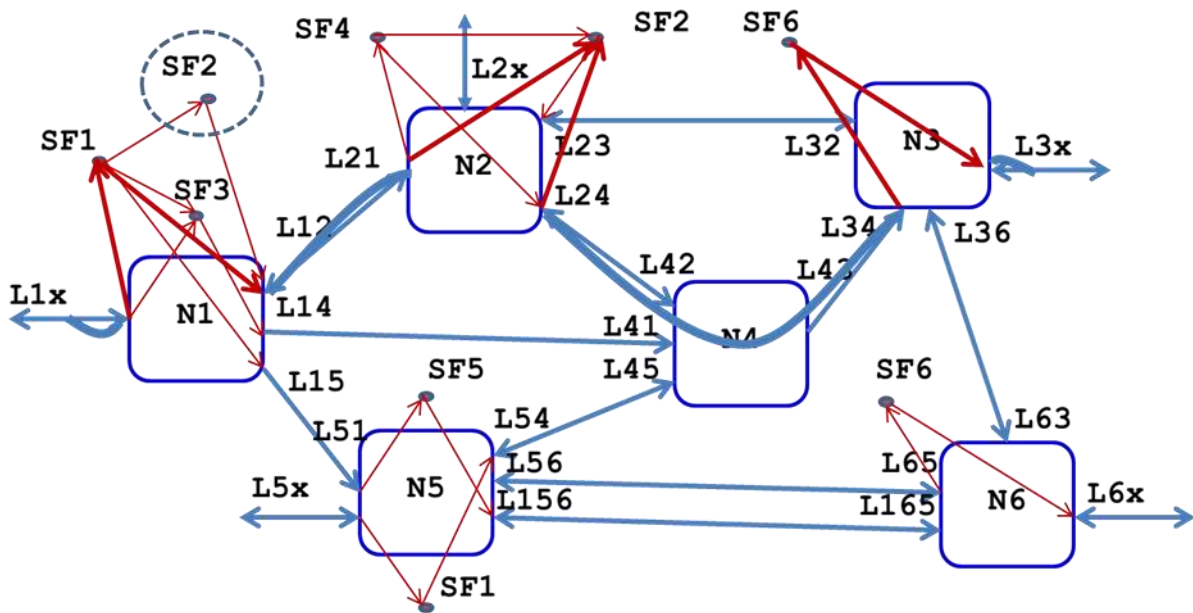


Figure 5: SFC recovery: SFC SF1-SF2-SF6 is recovered after SF2 on node N1 has failed

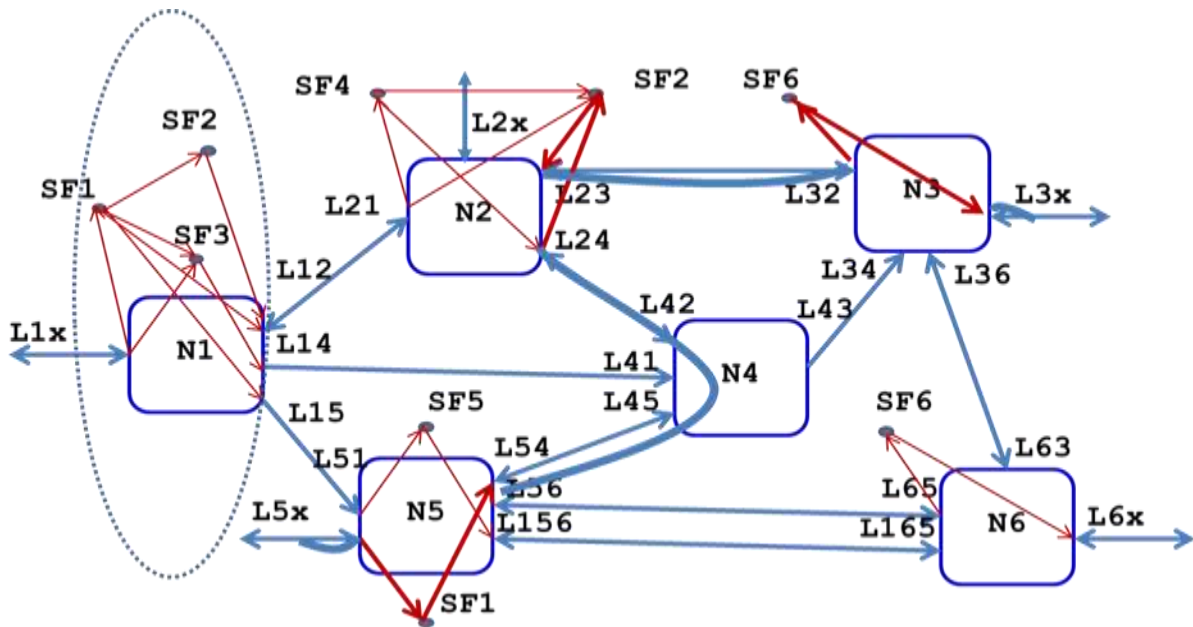


Figure 6: SFC recovery: SFC SF1-SF2-SF6 is recovered after node N1 has failed

### C.5. Network Clock Synchronization

Many current and future network applications (including 5g and IoT applications) require very accurate time services (PTP level, ns resolution). One way to implement the adequate network clock synchronization for such services is via describing network clocks as NFs on an NF-aware TE topology optimized to have best possible delay variation characteristics. Because such a topology will contain delay/delay variation metrics of topology links and node cross-connects, as well as costs in terms of delay/delay variation of connecting clocks to hosting them node link and tunnel termination points, it will be possible to dynamically select and provision bi-directional time-constrained deterministic paths or trees connecting clocks (e.g. grand master and boundary clocks) for the purpose of exchange of clock synchronization information. Note that network clock aware TE topologies separately provided by domain controllers will enable multi-domain network orchestrator to set up and manipulate the clock synchronization paths/trees spanning multiple network domains.

### C.6. Client - Provider Network Slicing Interface

3GPP defines network slice as "a set of network functions and the resources for these network functions which are arranged and configured, forming a complete logical network to meet certain network characteristics" [I-D.defoy-netslices-3gpp-network-slicing] [\_3GPP.28.801]. Network slice could be also defined as a logical partition of a provider's network that is owned and managed by a tenant. SF/NF-aware TE topology model has a potential to support a very important interface between network slicing clients and providers because, on the one hand, the model can describe holistically and hierarchically the client's requirements and preferences with respect to a network slice functional, topological and traffic engineering aspects, as well as of the degree of resource separation/ sharing between the slices, thus allowing for the client (up to agreed upon extent) to dynamically (re-)configure the slice or (re-)schedule said (re-)configurations in time, while, on the other hand, allowing for the provider to convey to the client the slice's operational state information and telemetry the client has expressed interest in.

### C.7. Dynamic Assignment of Regenerators for L0 Services

On large optical networks, some of provided to their clients L0 services could not be provisioned as single OCh trails, rather, as chains of such trails interconnected via regenerators, such as 3R regenerators. Current practice of the provisioning of such services requires configuration of explicit paths (EROs) describing identity

and location of regenerators to be used. A solution is highly desirable that could:

- o Identify such services based, for example, on optical impairment computations;
- o Assign adequate for the services regenerators dynamically out of the regenerators that are grouped together in pools and strategically scattered over the network topology nodes;
- o Compute and provision supporting the services chains of optical trails interconnected via so selected regenerators, optimizing the chains to use minimal number of regenerators, their optimal locations, as well as optimality of optical paths interconnecting them;
- o Ensure recovery of such chains from any failures that could happen on links, nodes or regenerators along the chain path.

NF-aware TE topology model (in this case L1 NF-aware L0 topology model) is just the model that could provide a network controller (or even a client controller operating on abstract NF-aware topologies provided by the network) to realize described above computations and orchestrate the service provisioning and network failure recovery operations (see Figure 7).

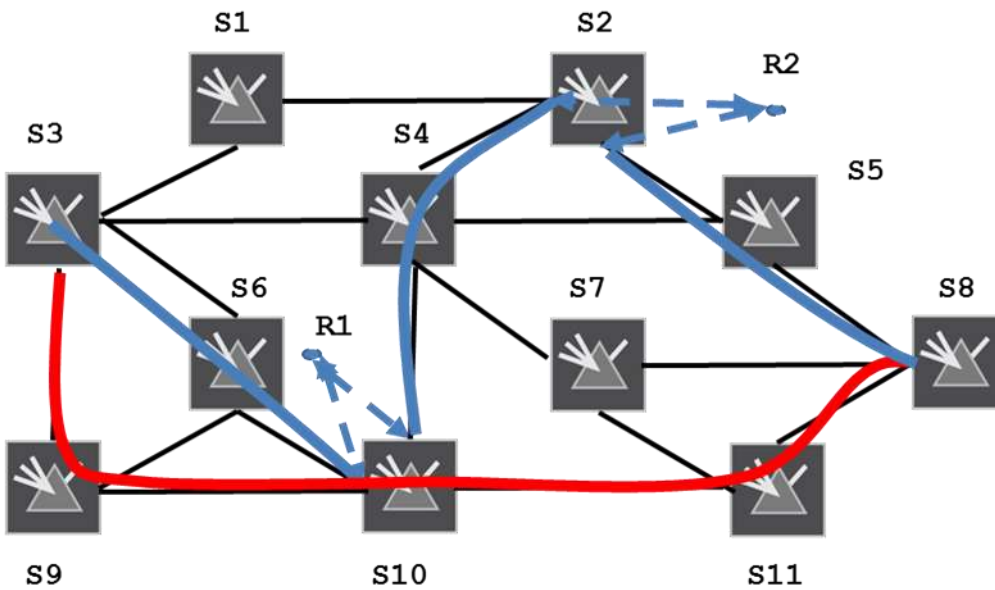


Figure 7: Optical tunnel as TE-constrained SFC of 3R regenerators. Red trail (not regenerated) is not optically reachable, but blue trail (twice regenerated) is

C.8. Dynamic Assignment of OAM Functions for L1 Services

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

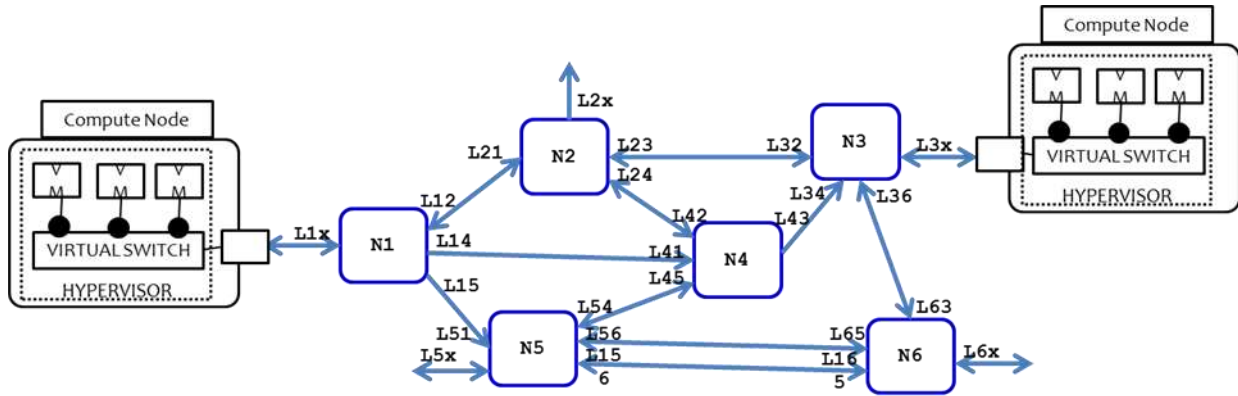


Figure 8: Compute/storage resource aware topology

C.9. SFC Abstraction and Scaling

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

C.10. Dynamic Compute/VM/Storage Resource Assignment

In a distributed data center network, virtual machines for compute resources may need to be dynamically re-allocated due to various reasons such as DCI network failure, compute resource load balancing, etc. In many cases, the DCI connectivity for the source and the destination is not predetermined. There may be a pool of sources and a pool of destination data centers associated with re-allocation of compute/VM/storage resources. There is no good mechanism to date to capture this dynamicity nature of compute/VM/storage resource reallocation. Generic Compute/VM/Storage resources can be described and announced as a SF, where a DC hosting these resources can be modeled as an abstract node. Topology interconnecting these abstract nodes (DCs) in general is of multi-domain nature. Thus, SF-aware topology model can facilitate a joint optimization of TE network resources and Compute/VM/Storage resources and solve Compute/VM/Storage mobility problem within and between DCs (see Figure 8).

### C.11. Application-aware Resource Operations and Management

Application stratum is the functional grouping which encompasses application resources and the control and management of these resources. These application resources are used along with network services to provide an application service to clients/end-users. Application resources are non-network resources critical to achieving the application service functionality. Examples of application resources include: caches, mirrors, application specific servers, content, large data sets, and computing power. Application service is a networked application offered to a variety of clients (e.g., server backup, VM migration, video cache, virtual network on-demand, 5G network slicing, etc.). The application servers that host these application resources can be modeled as an abstract node. There may be a variety of server types depending on the resources they host. Figure 9 shows one example application aware topology for video cache server distribution.

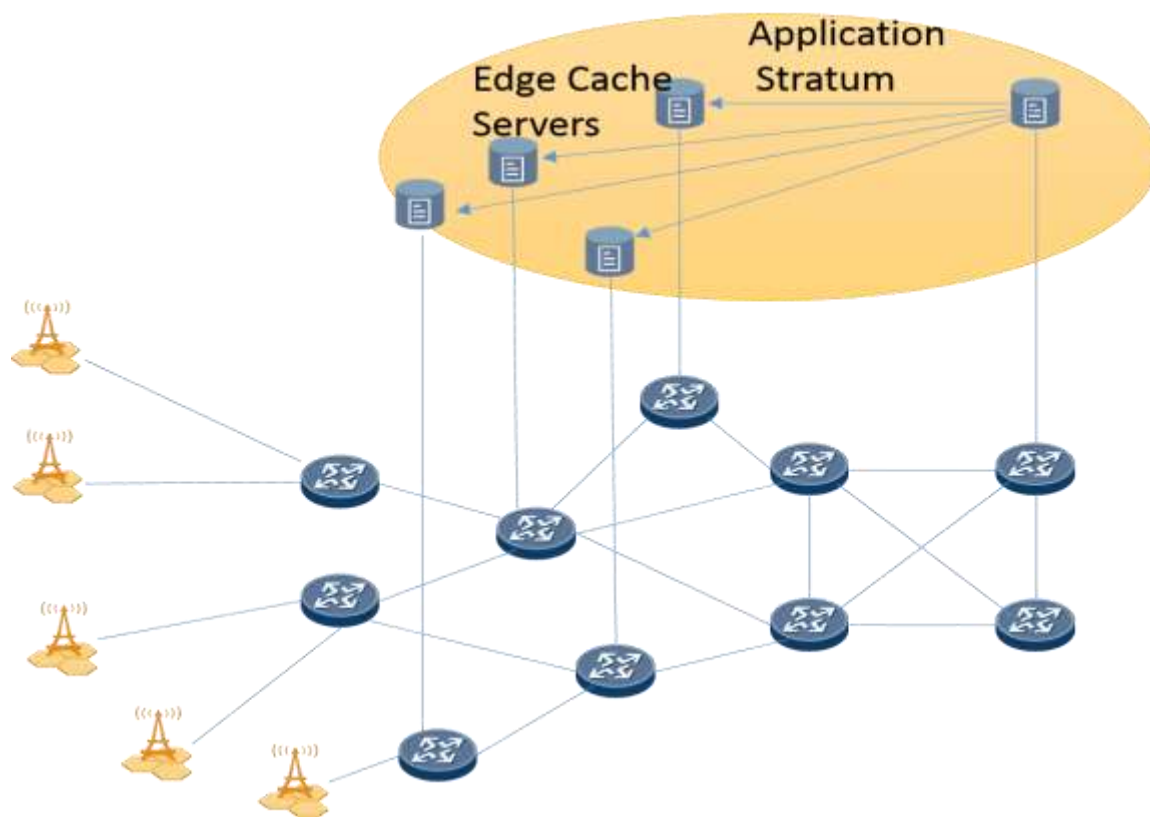


Figure 9: Application aware topology



### C.12. Interconnection between Service Functions/Termination Points in uCPE

Universal Customer Premises Equipment (uCPE) enables Virtual Network Functions (VNFs) at the client site. uCPE is based on the Network Function Virtualization Infrastructure (NFVI) - generally Linux distribution with integrated software that offers:

- o Virtual Switch functionality
- o Full virtualization/containerization solution
- o Data path acceleration tool-kits
- o Management layer

The sf-aware-topo-model placed in the controller controls via the management layer of uCPE the interconnection between:

- o virtual ports of VNFs
- o virtual ports of Virtual Switch abstraction elements
- o physical ports of uCPE

Figure 10 shows an example application aware topology for interconnection between Logical Network Elements [RFC8530], Network Instances [RFC8529], uCPE node Termination Points [RFC8345]. In Figure 10 the following elements are presented:

- o 3 Logical Network Elements (vCPEL3\_WAN1,vCPEL3\_WAN2,vSD-WAN)
- o 4 Network Instances (vCPEL2)
- o 4 Termination Points (Physical Ports)

There are two types of access provided to the client.

The 1st access "Internet" topology part: 1st uCPE Termination Point "WAN1\_port\_internet" -- NI (vCPEL2) -- LNE (vCPEL3\_telco\_internet) -- NI (vCPEL2) -- vSD-WAN\_port\_internet.

The 2nd access "MPLS" topology part: 2nd Termination Point "WAN2\_port\_mpls" -- NI (vCPEL2) -- LNE (vCPEL3\_telco\_mpls) -- NI (vCPEL2) -- vSD-WAN\_port\_mpls.

Finally SD-WAN balances the traffic via two WAN ports (Termination Points) of uCPE and shares the connection to LAN ports (Termination Points).

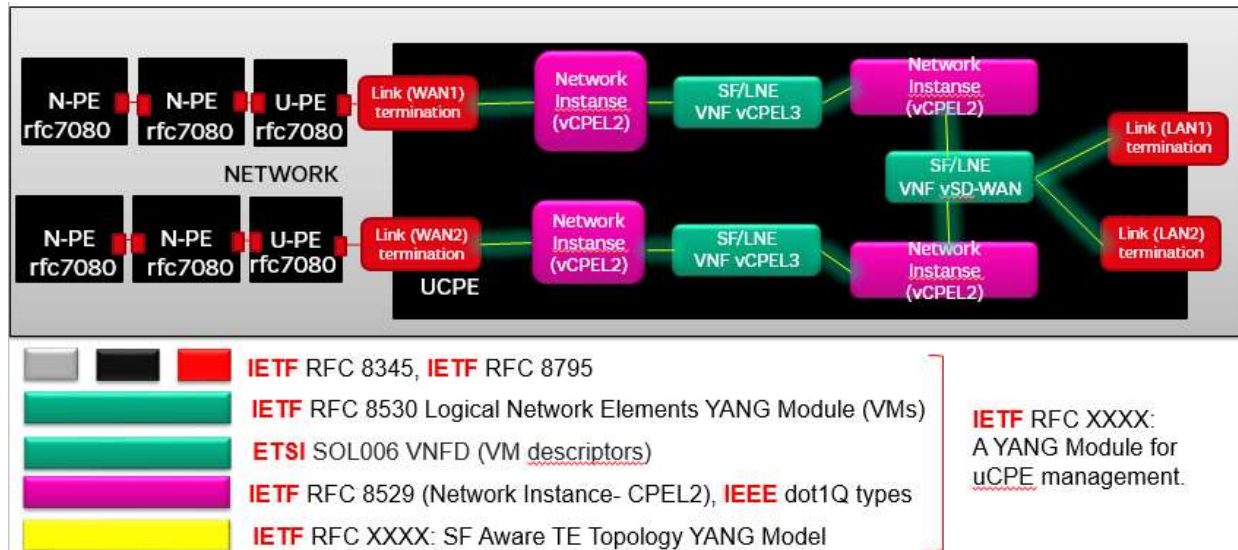


Figure 10: uCPE Service Functions topology

An example of an instance data tree in the XML format is presented in Figure 12, following the uCPE Service Functions topology presented in Figure 11.

For this example, the interconnection goes as follows: Network-facing Provider Edge (N-PE) router -- User-facing Provider Edge (U-PE) router -- uCPE ( Termination Point WAN -- NI (vCPEL2) -- LNE (vCPEL3) )

In uCPE, Termination Point (WAN) has id 1. On the NNI (connectionpoint\_id == 10) port of NI the trunk mode is configured. On UNI ports of NI (cp\_id == 13) access mode is configured. Port with cp\_id == 13 is connected to LNE cp\_id = 1.

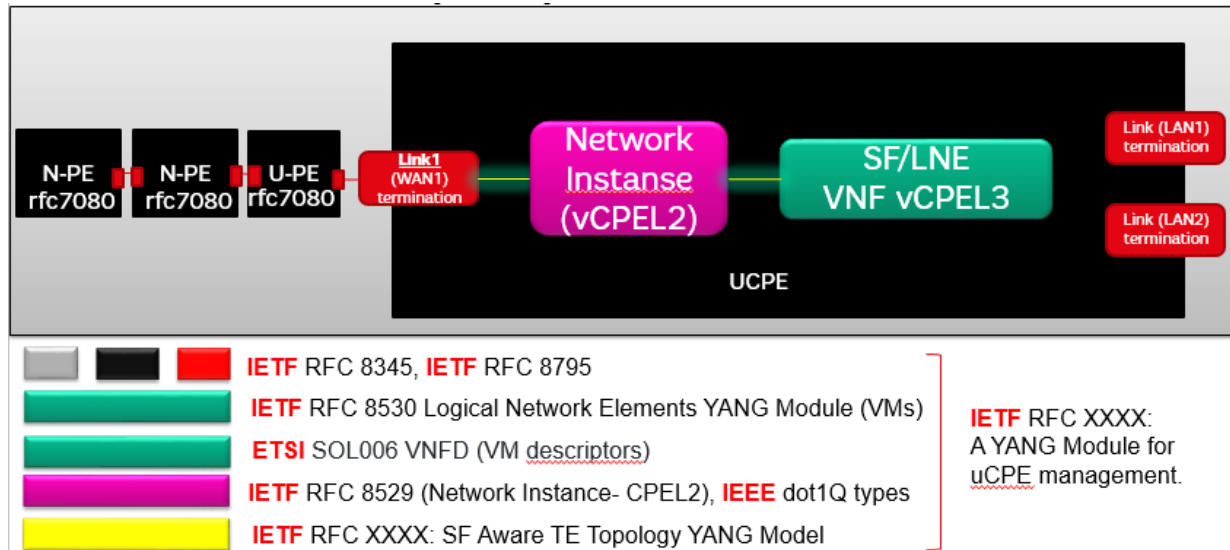


Figure 11: uCPE Service Functions topology (simple)

```

<config>
  <networks xmlns="urn:ietf:params:xml:ns:yang:ietf-network">
    <network>
      <network-id>network1</network-id>
      <network-types>
        <te-topology
          xmlns="urn:ietf:params:xml:ns:yang:ietf-te-topology">
          <sf xmlns=
            "urn:ietf:params:xml:ns:yang:ietf-te-topology-sf"/>
          </te-topology>
        </network-types>
      <node>
        <node-id>uCPE1</node-id>
        <termination-point
          xmlns=
            "urn:ietf:params:xml:ns:yang:ietf-network-topology">
          <tp-id>1</tp-id>
          <tp-properties
            xmlns=
              "urn:ietf:params:xml:ns:yang:ietf-ucpe-node-type">
          <ethernet>
            <duplex>full</duplex>
          </ethernet>
          <mtu>1500</mtu>
          <type>dppdk</type>
          </tp-properties>
        </node>
      </network>
    </networks>
  </config>

```

```

</termination-point>
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    "urn:ietf:params:xml:ns:yang:ietf-network-topology">
  <tp-id>2</tp-id>
</termination-point>
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</termination-point>
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  >0.0.0.0</te-node-id>
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  <te-node-attributes>
    <service-function
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      <connectivity-matrices>
        <connectivity-matrix>
          <id>1</id>
          <from>
            <service-function-id>CPEL3</service-function-id>
            <sf-connection-point-id
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          <to>
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            <sf-connection-point-id
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          </to>
          <enabled>true</enabled>
          <virtual-link-id>l10</virtual-link-id>
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        <link-termination>
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          <from>
            <tp-ref>1</tp-ref>
          </from>
          <to>
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          </to>
          <virtual-link-id

```

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</link-terminations>
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</node>
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  <termination-point
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    "urn:ietf:params:xml:ns:yang:ietf-network-topology">
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  </termination-point>
  <termination-point
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  </termination-point>
</node>
<node>
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  <termination-point
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  </termination-point>
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```
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  <tp-id>3</tp-id>
</termination-point>
<termination-point
  xmlns=
    "urn:ietf:params:xml:ns:yang:ietf-network-topology">
  <tp-id>4</tp-id>
</termination-point>
</node>
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  <source-node>N-PE</source-node>
  <source-tp>2</source-tp>
</source>
<destination>
  <dest-node>U-PE</dest-node>
  <dest-tp>1</dest-tp>
</destination>
</link>
<link
  xmlns="urn:ietf:params:xml:ns:yang:ietf-network-topology">
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  <dest-tp>1</dest-tp>
</destination>
</link>
</network>
</networks>
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    "urn:ietf:params:xml:ns:yang:ietf-logical-network-element">
<logical-network-element>
  <name>CPEL3</name>
  <logical-network-element-properties
    xmlns=
      "urn:ietf:params:xml:ns:yang:ietf-ucpe-lne-properties">
  <etsi>
  <vnfd>CPEL3</vnfd>
  <vdu>small</vdu>
```

```

    </etsi>
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</logical-network-element>
</logical-network-elements>
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  <network-instance>
    <name>CPEL2</name>
    <network-instance-properties
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          <trunk-allowed-vlans>Y</trunk-allowed-vlans>
          <trunk-allowed-vlans>Z</trunk-allowed-vlans>
        </dot1q-vlan>
      </sf-connection-points>
      <sf-connection-points>
        <sf-connection-point-id>11</sf-connection-point-id>
        <dot1q-vlan>
          <access-tag>X</access-tag>
        </dot1q-vlan>
      </sf-connection-points>
      <sf-connection-points>
        <sf-connection-point-id>12</sf-connection-point-id>
        <dot1q-vlan>
          <access-tag>Z</access-tag>
        </dot1q-vlan>
      </sf-connection-points>
      <sf-connection-points>
        <sf-connection-point-id>13</sf-connection-point-id>
        <dot1q-vlan>
          <access-tag>Y</access-tag>
        </dot1q-vlan>
      </sf-connection-points>
      <ni-area>wan</ni-area>
      <supporting-node>uCPE1</supporting-node>
    </network-instance-properties>
  </network-instance>
</network-instances>
</config>

```

Figure 12: uCPE Service Functions topology YIN example

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