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I. Busi
Huawei
D. King
Old Dog Consulting
H. Zheng
Huawei
Y. Xu
CAICT

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Abstract

This document provides an analysis of the applicability of the YANG models defined by the IETF (Traffic Engineering Architecture and Signaling (TEAS) moreover, Common Control and Measurement Plane (CCAMP) WGs in particular) to support ODU transit services, Transparent client services and EPL/EVPL Ethernet services over OTN single and multi-domain network scenarios.

This document also describes how existing YANG models can be used through a number of worked examples and JSON fragments.

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1. Introduction

Transport network domains, including Optical Transport Network (OTN) and Wavelength Division Multiplexing (WDM) networks, are typically deployed based on a single vendor or technology platforms. They are often managed using proprietary interfaces to dedicated Element Management Systems (EMS), Network Management Systems (NMS) and increasingly Software Defined Network (SDN) controllers.

Support of packet connectivity services over transport network domains are critical for a wide range of applications and services, including data center and LAN interconnects, Internet service backhauling, mobile backhaul and enterprise Carrier Ethernet services. A clear goal of operators is to automate the setup of these connectivity services across multiple transport network domains, that may utilize different technologies.

A well-defined common open interface to each domain controller or a management system is required for network operators to control multi-vendor and multi-domain networks and also enable coordination and automation of service provisioning. This is facilitated by using standardized data models (e.g., YANG models), and an appropriate protocol (e.g., RESTCONF [RFC8040]).

This document examines the applicability of the YANG models being defined by IETF (Traffic Engineering Architecture and Signaling (TEAS) moreover, Common Control and Measurement Plane (CCAMP) WGs in particular) to support Optical Transport Networks (OTN) single and multi-domain scenarios.

1.1. The Scope of this Document

This document assumes a reference architecture, including interfaces, based on the Abstraction and Control of Traffic-Engineered Networks (ACTN), defined in [RFC8453].

The focus of this document is on the interface between the Multi Domain Service Coordinator (MDSC) and a Provisioning Network Controller (PNC), controlling a transport network domain, called MDSC-PNC Interface (MPI) in [RFC8453].

It is worth noting that the same MPI analyzed in this document could be used between hierarchical MDSC controllers, as shown in Figure 4 of [RFC8453].

Detailed analysis of the interface between the Customer Network Controller (CNC) and the MDSC, called CNC-MDSC Interface (CMI) in [RFC8453], as well as of the interface between service and network orchestrators are outside the scope of this document. However, when needed, this document describes some considerations and assumptions about the information which needs to be provided at these interfaces.

The list of the IETF YANG models which are applicable to the ACTN MPI can be found in [ACTN-YANG].

The Functional Requirements for the transport API as described in the Optical Networking Foundation (ONF) document [ONF TR-527] have been taken as input for defining the reference scenarios analyzed in this document.

The analysis provided in this document confirms that the IETF YANG models defined in [RFC8345], [TE-TOPO], [OTN-TOPO], [CLIENT-TOPO], [TE-TUNNEL], [PATH-COMPUTE], [OTN-TUNNEL] and [CLIENT-SIGNAL] can be used together to control a multi-domain OTN network to support different types of multi-domain services, such as ODU transit services, Transparent client services and EPL/EVPL Ethernet services, over a multi-domain OTN connection, satisfying also the requirements in [ONF TR-527].

2. Terminology

Domain: A domain, as defined in [RFC4655], is "any collection of network elements within a common sphere of address management or path computation responsibility". Specifically, within this document, we mean a part of an operator's network that is under common management (i.e., under shared operational management using the same instances of a tool and the same policies). Network elements will often be grouped into domains based on technologies, vendor profiles, or geographic proximity.

CNC: Customer Network Controller

Connection: The data plane configuration of an LSP, within this document it is typically an ODU LSP. An end-to-end connection/LSP represents an entire connection/LSP between the connection/LSP node end-points. A connection/LSP segment represents a portion of the end-to-end connection/LSP.

Connectivity Service: A service, or connectivity service, in the context of this document can be considered as some form of connectivity service between customer sites across the network operator's network [RFC8309].

E-LINE: Ethernet Line

EPL: Ethernet Private Line

EVPL: Ethernet Virtual Private Line

ILL: Inter-Layer Lock

Link: A link, or a physical link, is used to reprent the adjacency between two physical nodes. The term OTN link represents a link between two OTN switching physical nodes.

LSP: Label Switched Path

LTP: Link Termination Point

MDSC: Multi-Domain Service Coordinator

Network Configuration: As described in [RFC8309] it describes the instructions provided to a controller on how to configure parts of a network.

ODU: Optical Channel Data Unit

OTU: Optical Channel Transport Unit

OTN: Optical Transport Network

PNC: Provisioning Network Controller

Protection Switching: Protection switching, as defined in [ITU-T G.808.1] and [RFC4427], provides the capability to swith the traffic in case of network failurs over pre-allocated networks resourse. Typically linear protection methods would be used and configured to operate as 1+1 unidirectional, 1+1 bidirectional or 1:n bidirectional. This ensures fast and simple service survivability.

Protection Transport Entity/LSP: A protection transport entity/LSP, as defined in [ITU-T G.808.1] and [RFC4427], represents the path where the "normal" user traffic is transported during protection switching events (e.g., when the working transport entity/LSP fails).

Restoration: Restoration methods, as defined in [RFC4427], provide the capability to reroute and restore traffic around network failures without the necessity to allocate network resources as required for dedicated 1+1 protection schemes. On the other hand, restoration times are typically longer than protection switching times.

Service Model: As described in [RFC8309] it describes a service and the parameters of the service in a portable way that can be used uniformly and independent of the equipment and operating environment.

TE Link: As defined in [TE-TOPO], it is an element of a TE topology, presented as an edge on TE graph.

TE Tunnel: As defined in [TE-TUTORIAL], it is a connection-oriented service provided by a layer network of delivery of a client's data between source and destination tunnel termination points.

TE Tunnel Segment: As defined in [TE-TUTORIAL], it is a part of a multi-domain TE tunnel that spans.

TE Tunnel Hand-off: As defined in [TE-TUTORIAL], it is an access link or inter-domain link by which a multi-domain TE tunnel enters or exits a given network domain.

Note - The three definitions above are currently in [TE-TUTORIAL] but it is expected that they will be moved to [TE-TUNNEL]. When this happens, the reference will be updated and the [TE-TUTORIAL] reference will be downgraded to Informative.

TPN: Tributary Port Number

TTP: Tunnel Termination Point

Termination and Adaptation: It represents the termination of a server-layer connection at the node edge-point and the adaptation/mapping of the client layer traffic over the terminated server-layer connection.

Transparent Client: As defined in [CLIENT-SIGNAL], it represents a client-layer signal, such as Ethernet physical interfaces, FC, STM-n, that cannot be switched but only mapped over a server-layer TE Tunnel.

Working Transport Entity/LSP: A working transport entity/LSP, as defined in [ITU-T G.808.1] and [RFC4427], represents the path where the "normal" user traffic is transported.

UNI: User Network Interface

3. Conventions Used in this Document

3.1. Topology and Traffic Flow Processing

The traffic flow between different nodes is specified as an ordered list of nodes, separated with commas, indicating within the brackets the processing within each node:

```
<node> [<processing>]{, <node> [<processing>]}
```

The order represents the order of traffic flow being forwarded through the network.

The <processing> represents the type of processing performed by the node, which can be just switching at a given layer "(switching-layer)" or it can also include an adaptation of a client layer into a server layer: "(client-layer) -> server-layer" or "client-layer -> (server-layer)", where the round brackets are used to represent at which layer (client layer or server layer) the node is switching.

For example, the following traffic flow:

```
R1 [(PKT) -> ODU2], S3 [(ODU2)], S5 [(ODU2)], S6 [(ODU2)],
R3 [ODU2 -> (PKT)]
```

Node R1 is switching at the packet (PKT) layer and mapping packets into an ODU2 before transmission to node S3. Nodes S3, S5 and S6, are switching at the ODU2 layer: S3 sends the ODU2 traffic to S5, which then sends it to S6 which finally sends to R3. Node R3 terminates the ODU2 from S6 before switching at the packet (PKT) layer.

The paths of working and protection transport entities are specified as an ordered list of nodes, separated with commas:

```
<node> {, <node>}
```

The order represents the order of traffic flow being forwarded through the network in the forward direction. In the case of bidirectional paths, the forward and backward directions are selected arbitrarily, but the convention is consistent between working/protection path pairs, as well as across multiple domains.

3.2. JSON code

This document provides some detailed JSON code examples to describe how the YANG models being developed by the IETF (TEAS and CCAMP WG in particular) may be used. The scenario examples are provided using JSON to facilitate readability.

Different objects need to have an identifier. The convention used to create mnemonic identifiers is to use the object name (e.g., S3 for node S3), followed by its type (e.g., NODE), separated by an "-", followed by "-ID". For example, the mnemonic identifier for node S3 would be S3-NODE-ID.

The JSON language does not support the insertion of comments that have been instead found to be useful when writing the examples. This document will insert comments into the JSON code as JSON name/value pair with the JSON name string starting with the "//" characters. For example, when describing the example of a TE Topology instance representing the ODU Abstract Topology exposed by the Transport PNC, the following comment has been added to the JSON code:

```
"// comment": "ODU Abstract Topology @ MPI",
```

The JSON code examples provided in this document have been validated against the YANG models following the validation process described in Appendix A, which would not consider the comments.

To have successful validation of the examples, some numbering scheme has been defined to assign identifiers to the different entities which would pass the syntax checks. In that case, to simplify the reading, another JSON name/value pair formatted as a comment and using the mnemonic identifiers is also provided. For example, the identifier of node S3 (S3-NODE-ID) has been assumed to be "10.0.0.3" and would be shown in the JSON code example using the two JSON name/value pair:

```
   "// te-node-id": "S3-NODE-ID",

   "te-node-id": "10.0.0.3",
```

The first JSON name/value pair will be automatically removed in the first step of the validation process, while the second JSON name/value pair will be validated against the YANG model definitions.

4. Scenarios Description

4.1. Reference Network

The physical topology of the reference network is shown in Figure 1. It represents an OTN network composed of three transport network domains which provide connectivity services to an IP customer network through nine access links:

```
               ........................
   .........   :                      :
           :   :   Network domain 1   :   .............
   Customer:   :                      :   :           :
    domain :   :     S1 -------+      :   :  Network  :
           :   :    /           \     :   :  domain 3 :   ..........
       R1 ------- S3 ----- S4    \    :   :           :   :
           :   :    \        \    S2 --------+        :   :Customer
           :   :     \        \    |  :   :   \       :   : domain
           :   :      S5       \   |  :   :    \      :   :
       R2 ------+    /  \       \  |  :   :    S31 --------- R5
           :   : \  /    \       \ |  :   :   /   \   :   :
       R3 ------- S6 ---- S7 ---- S8 ------ S32   S33 ------ R6
           :   : /        |       |   :   : / \   /   :   :.......
       R4 ------+         |       |   :   :/   S34    :          :
           :   :..........|.......|...:   /    /      :          :
   ........:              |       |      /:.../.......:          :
                          |       |     /    /                   :
               ...........|.......|..../..../...                 :
               :          |       |   /    /   :    ..............
               : Network  |       |  /    /    :    :
               : domain 2 |       | /    /     :    :Customer
               :         S11 ---- S12   /      :    : domain
               :        /          | \ /       :    :
               :     S13     S14   | S15 ------------- R7
               :     |  \   /   \  |    \      :    :
               :     |   S16     \ |     \     :    :
               :     |  /        S17 -- S18 --------- R8
               :     | /            \   /      :    :
               :    S19 ---- S20 ---- S21 ------------ R9
               :                               :    :
               :...............................:    :.............
```

Figure 1 - Reference network

This document assumes that all the Si transport network switching nodes are capable of switching in the electrical domain (ODU switching) moreover, that all the Si-Sj OTN links within the transport network (intra-domain or inter-domain) are 100G links while the access Ri-Sj links are 10G links.

This document also assumes that within the transport network, the physical/optical connections supporting the Si-Sj OTN links (up to the OTU4 trail), are pre-provisioned using mechanisms which are outside the scope of this document and are not exposed at the MPIs to the MDSC.

Different transmission technologies can be used on the access links (e.g., Ethernet, STM-N and OTU). Section 4.3 provides more details about the different assumptions on the access links for different types of connectivity services and section 4.4 describes the control of access links which can support different technology configurations (e.g., STM-64, 10GE or OTU2) depending on the type of service being configured (multi-function access links).

To carry client signals (e.g., Ethernet or STM-N) over OTN, some ODU termination and adaptation resources need to be available on the physical edge nodes (e.g., node S3 and S18). The location of these resources within the physical node is implementation specific and outside the scope of standardization. This document assumes that these termination and adaptation resources are located on the physical interfaces of the edge nodes terminating the access links. In other words, each physical access link has a set dedicated ODU termination and adaptation resources.

The transport network control architecture, shown in Figure 2, follows the ACTN architecture as defined in the ACTN framework document [RFC8453], and uses the same functional components:

```
                           --------------
                          |              |
                          |     CNC      |
                          |              |
                           --------------
                                 |
             ....................|....................... CMI
                                 |
                          ----------------
                         |                |
                         |      MDSC      |
                         |                |
                          ----------------
                            /   |    \
                           /    |     \
            ............../.....|......\................ MPIs
                         /      |       \
                        /   ----------   \
                       /   |   PNC2   |   \
                      /     ----------     \
             ----------         |           \
            |   PNC1   |      -----          \
             ----------     (       )      ----------
                 |         (         )    |   PNC3   |
               -----      (  Network  )    ----------
             (       )    (  Domain 2 )        |
            (         )    (         )       -----
           (  Network  )    (       )      (       )
           (  Domain 1 )      -----       (         )
            (         )                  (  Network  )
             (       )                   (  Domain 3 )
               -----                      (         )
                                           (       )
                                             -----
```

Figure 2 - Controlling Hierarchies

The NEs within network domains 1, 2 and 3 of Figure 1 are controlled, respectively, by PNC1, PNC2 and PNC3 of Figure 2. The MDSC control the end-to-end network through the MPIs toward the underlying PNCs.

The ACTN framework facilitates the separation of the network and service control from the underlying technology. It helps the customer to define the network as desired by business needs. The CMI is defined to keep a minimal level of dependency (or no dependency at all) from the underlying network technologies. The MPI instead requires some specialization according to the domain technology.

The control interfaces within the scope of this document are the three MPIs, as shown in Figure 2.

The split of functionality at the MPI in the ACTN architecture between the MDSC (multi-domain controller) and the PNCs (domain controllers), is equivalent to separation functionality assumed in the ONF T-API interface, as described in the ONF T-API multi-domain use cases [ONF TR-527]. Furthermore, this functional separation is similarly defined in the MEF PRESTO interface between the Service Orchestration Functionality (SOF) and the Infrastructure Control and Management (ICM) in the MEF LSO Architecture [MEF 55].

This document does not make any assumption about the control architecture of the customer IP network: in line with [RFC8453], the CNC is just a functional component within the customer control architecture which is capable of requesting connectivity services on demand between IP routers at the CMI.

The CNC can request connectivity services between IP routers which can be attached to different transport network domains (e.g., between R1 and R8 in Figure 1) or to the same transport network domain (e.g., between R1 and R3 in Figure 1). Since the CNC is not aware of the transport network controller hierarchy, the mechanisms used by the CNC to request connectivity services at the CMI is also unaware whether the requested service spans a single-domain or multi-domains.

It is assumed that the CMI allows the CNC to provide all the necessary information needed by the MDSC to understand the connectivity service request and to determine the network configurations to be requested, at the MPIs, to its underlying PNCs to support the requested connectivity service.

The MDSC, after having received a single-domain service request from the CNC at the CMI (e.g., between R1 and R3 in Figure 1), can follow the same procedures, described above for the multi-domain service, and decide the network configuration to request only at the MPI of the PNC controlling that domain (e.g., MPI1 of PNC1 in Figure 2).

4.2. Topology Abstractions

Abstraction provides a selective method for representing connectivity information within a domain. There are multiple methods to abstract a network topology. This document assumes the abstraction method defined in [RFC7926]:

> "Abstraction is the process of applying the policy to the available TE information within a domain, to produce selective information that represents the potential ability to connect across the domain. Thus, abstraction does not necessarily offer all possible connectivity options, but presents a general view of potential connectivity according to the policies that determine how the domain's administrator wants to allow the domain resources to be used."

[RFC8453] Provides the context of topology abstraction in the ACTN architecture and discusses a few alternatives for the abstraction methods for both packet and optical networks. This is an important consideration since the choice of the abstraction method impacts protocol design and the information it carries. According to [RFC8453], there are three types of topologies:

- White topology: This is a case where the PNC provides the actual network topology to the MDSC without any hiding or filtering. In this case, the MDSC has the full knowledge of the underlying network topology;

- Black topology: The entire domain network is abstracted as a single virtual node with the access links and inter-domain links without disclosing any node internal connectivity information;

- Grey topology: This abstraction level is between black topology and white topology from a granularity point of view.

Each PNC should provide the MDSC a network topology abstraction hiding the internal details of the physical domain network topology controlled by the PNC. As described in section 3 of [RFC8453], the level of abstraction provided by each PNC is based on the PNC configuration parameters and it is independent of the abstractions provided by other PNCs. Therefore, it is possible that different PNCs provide different types of topology abstractions. The MDSC can operate on each MPI abstract topology regardless of, and independently from, the type of abstraction provided by its underlying PNC.

For analyzing how the MDSC can operate on an abstract topology provided by several PNCs that independently applied different abstraction policies and therefore provided different types of abstract topologies, the following assumptions are made for the reference network in Figure 1:

o PNC1 and PNC2 provide black topology abstractions which expose at MPI1, and MPI2 respectively, a single virtual node (representing the whole network domain 1, and domain 2 respectively).

o PNC3 provides a white topology abstraction which exposes at MPI3 all the physical nodes and links within network domain 3.

The MDSC should be capable of stitching together the abstracted topologies provided by each PNC to build its view of the multi-domain network topology. This topology knowledge may require proper oversight, including the application of local policy, configuration methods, and the application of a trust model. Methods of how to manage these aspects are out of scope for this document, but recomandations are provided in the Security section of this document.

The MDSC can also provide topology abstraction of its view of the multi-domain network topology at its CMIs depending on the customers' needs and policies: it can provide different types of topology abstractions at different CMIs. Analyzing the topology abstractions provided by the MDSC to its CMIs is outside the scope of this document.

4.3. Service Configuration

In the following scenarios, it is assumed that the CNC is capable of requesting connectivity services from the MDSC, for example to interconnect IP routers.

The type of connectivity services depends on the type of physical links (e.g. OTN link, ETH link or SDH link) between the routers and transport network.

The packet processing inside IP routers, including packet encapsualation and decapsulation, Ri (PKT -> foo) and Rj (foo ->

PKT), are assumed to be performed by means that are not under the control of, and not visible to, the MDSC nor to the PNCs. Therefore, these mechanisms are outside the scope of this document.

4.3.1. ODU Transit

The physical links interconnecting the IP routers and the transport network can be 10G OTN links.

In this case, it is assumed that the physical/optical interconnections below the ODU layer (up to the OTU2 trail) are pre-provisioned using mechanisms which are outside the scope of this document and not exposed at the MPIs between the PNCs and the MDSC.

For simplicity of the description, it is also assumed that these interfaces are not channelized (i.e., they can only support one ODU2).

When a 10Gb IP link between R1 and R8 is needed, an ODU2 end-to-end connection needs to be created, passing through transport network nodes S3, S1, S2, S31, S33, S34, S15 and S18 which belong to different PNC domains (multi-domain service request):

```
R1 [(PKT) -> ODU2], S3 [(ODU2]), S1 [(ODU2]), S2 [(ODU2]),
S31 [(ODU2)], S33 [(ODU2)], S34 [(ODU2)],
S15 [(ODU2)], S18 [(ODU2)], R8 [ODU2 -> (PKT)]
```

The MDSC receives, at the CMI,the request to create an ODU2 transit service between the access links on S3 and S18, which belong to different PNC domains (multi-domain service request). The MDSC also determines the network configuration requests to be sent to its underlying PNCs, at the MPIs, to coordinate the setup of a multi-domain ODU2 connection segment between the access links on S3 and S18.

When a 10Gb IP link between R1 and R3 is needed, an ODU2 end-to-end connection needs to be created, passing through transport network nodes S3, S5 and S6 which belong to the same PNC domain (single-domain service request):

```
R1 [(PKT) -> ODU2], S3 [(ODU2)], S5 [(ODU2)], S6 [(ODU2)],
R3 [ODU2 -> (PKT)]
```

As described in section 4.1, the mechanisms, used by the CNC at the CMI, are independent on whether the service request is single-domain service or multi-domain.

The MDSC can figure out that it needs to setup an ODU2 transit service between the access links on S3 and S6, which belong to the same PNC domain (single-domain service request) and it decides the proper network configuration to request PNC1.

4.3.2. EPL over ODU

The physical links interconnecting the IP routers and the transport network can be 10G Ethernet physical links (10GE).

In this case, it is assumed that the Ethernet physical interfaces (up to the MAC layer) are pre-provisioned using mechanisms which are outside the scope of this document and not exposed at the MPIs between the PNCs and the MDSC.

When a 10Gb IP link between between R1 and R8 is needed, an EPL service needs to be created, supported by an ODU2 end-to-end connection, between transport network nodes S3 and S18, passing through transport network nodes S1, S2, S31, S33, S34 and S15, which belong to different PNC domains (multi-domain service request):

```
R1 [(PKT) -> ETH], S3 [ETH -> (ODU2)], S1 [(ODU2)],
S2 [(ODU2)], S31 [(ODU2)), S33 [(ODU2)], S34 [(ODU2)],
S15 [(ODU2)], S18 [(ODU2) -> ETH], R8 [ETH -> (PKT)]
```

The MDSC receives, at the CMI, the request to create an EPL service between the access links on S3 and S18, which belong to different PNC domains (multi-domain service request). The MDSC determines the network configurations to request, at the MPIs, to its underlying PNCs, to coordinate the setup of an end-to-end ODU2 connection between the nodes S3 and S8, including the configuration of the adaptation functions inside these edge nodes, such as S3 [ETH -> (ODU2)] and S18 [(ODU2) -> ETH].

When a 10Gb IP link between R1 and R2 is needed, an EPL service needs to be created, supported by an ODU2 end-to-end connection between transport network nodes S3 and S6, passing through the transport network node S5, which belong to the same PNC domain (single-domain service request):

```
R1 [(PKT) -> ETH], S3 [ETH -> (PKT)] S5 [(ODU2)],
S6 [(ODU2) -> ETH], R2 [ETH -> (PKT)]
```

As described in section 4.1, the mechanisms used by the CNC at the CMI are independent on whether the service request is single-domain service or multi-domain.

Based on the assumption above, in this case, the MDSC can figure out that it needs to setup an EPL service between the access links on S3 and S6, which belong to the same PNC domain (single-domain service request) and it decides the proper network configuration to request PNC1.

4.3.3. Transparent Client Services

[ITU-T G.709] defines mappings of different Transparent Client layers into ODU. Most of them are used to provide Private Line services over an OTN transport network supporting a variety of types of physical access links (e.g., Ethernet, SDH STM-N, Fibre Channel, InfiniBand, etc.) interconnecting the IP routers and the transport network.

When a 10Gb IP link between R1 and R8 is needed, using, for example SDH physical links between the IP routers and the transport network, an STM-64 Private Line service needs to be created, supported by an ODU2 end-to-end connection, between transport network nodes S3 and S18, passing through transport network nodes S1, S2, S31, S33, S34 and S15, which belong to different PNC domains (multi-domain service request):

```
R1 [(PKT) -> STM-64], S3 [STM-64 -> (ODU2)], S1 [(ODU2)],
S2 [(ODU2)], S31 [(ODU2)], S33 [(ODU2)], S34[(ODU2)],
S15 [(ODU2)], S18 [(ODU2) -> STM-64], R8 [STM-64 -> (PKT)]
```

As described (section 4.1) the CNC provides the essential information to permit the MDSC to compute which type of service is needed, in this case, an STM-64 Private Line Service between the access links on S3 and S8, and it also decides the network configurations, including the configuration of the adaptation functions inside these edge nodes, such as S3 [STM-64 -> (ODU2)] and S18 [(ODU2) -> STM-64].

When a 10Gb IP link between R1 and R3 is needed, an STM-64 Private Line service needs to be created between R1 and R3 (single-domain service request):

```
R1 [(PKT) -> STM-64], S3[STM-64 -> (ODU2)], S5 [(ODU2)],
S6 [(ODU2) -> STM-64], R3[STM-64 -> (PKT)]
```

As described in section 4.1, the mechanisms, used by the CNC at the CMI, are independent on whether the service request is single-domain service or multi-domain.

Based on the assumption above, in this case, the MDSC can figure out that it needs to setup an STM-64 Private Line service between the access links on S3 and S6, which belong to the same PNC domain (single-domain service request) and it decides the proper network configuration to request PNC1.

4.3.4. EVPL over ODU

When the physical links interconnecting the IP routers and the transport network are Ethernet physical links, it is also possible that different Ethernet services (e.g., EVPL) can share the same physical access link using different VLANs.

As described in section 4.3.2, it is assumed that the Ethernet physical interfaces (up to the MAC layer) are pre-provisioned.

When two 1Gb IP links between R1 to R2 and between R1 and R8 are needed, two EVPL services need to be created, supported by two ODU0 end-to-end connections:

```
R1 [(PKT) -> VLAN], S3 [VLAN -> (ODU0)], S5 [(ODU0)],
S6 [(ODU0) -> VLAN], R2 [VLAN -> (PKT)]

R1 [(PKT) -> VLAN], S3[VLAN -> (ODU0)], S1 [(ODU0)],
S2 [(ODU0)], S31 [(ODU0)], S33 [(ODU0)], S34 [(ODU0)],
S15 [(ODU0)], S18 [(ODU0) -> VLAN], R8[VLAN -> (PKT)]
```

It is worth noting that the first EVPL service is required between access links which belong to the same PNC domain (single-domain service request) while the second EVPL service is required between access links which belong to different PNC domains (multi-domain service request).

Since the two EVPL services are sharing the same Ethernet physical link between R1 and S3, different VLAN IDs are associated with different EVPL services: for example, VLAN IDs 10 and 20 respectively.

Based on the assumptions described in section 4.3.2, the CNC sends a request to the MDSC, at the CMI, to setup these EVPL services. The MDSC will determine the network configurations to request to the underlying PNCs, as described in section 4.3.2.

4.4. Multi-function Access Links

Some physical links interconnecting the IP routers and the transport network can be configured in different modes, e.g., as OTU2 trail or STM-64 or 10GE physical links.

This configuration can be pre-provisioned by means which are outside the scope of this document. In this case, these links will appear at the MPI as links supporting only one mode (depending on how the link has been pre-provisioned) and will be controlled at the MPI as discussed in section 4.3: for example, a 10G multi-function access link can be pre-provisioned as an OTU2 trail (section 4.3.1), a 10GE physical link (section 4.3.2) or an STM-64 physical link (section 4.3.3).

It is also possible not to configure these links a-priori and let the MDSC (or, in case of a single-domain service request, the PNC) decide how to configure these links, based on the service configuration.

For example, if the physical link between R1 and S3 is a multi-functional access link while the physical links between R4 and S6 and between R8 and S18 are STM-64 and 10GE physical links respectively, it is possible to configure either an STM-64 Private Line service between R1 and R4 or an EPL service between R1 and R8.

The traffic flow between R1 and R4 can be summarized as:

```
R1 [(PKT) -> STM-64], S3 [STM-64 -> (ODU2)], S5 [(ODU2)],
S6 [(ODU2) -> STM-64], R4 [STM-64 -> (PKT)]
```

The traffic flow between R1 and R8 can be summarized as:

```
R1 [(PKT) -> ETH], S3 [ETH -> (ODU2)], S1 [(ODU2)],
S2 [(ODU2)], S31 [(ODU2)), S33 [(ODU2)], S34 [(ODU2)],
S15 [(ODU2)], S18 [(ODU2) -> ETH], R8 [ETH -> (PKT)]
```

The CNC is capable of requesting, via the CMI, the setup either an STM-64 Private Line service, between R1 and R4, or an EPL service, between R1 and R8.

The MDSC, based on the service being request, decides the network configurations to request, at the MPIs, to its underlying PNCs, to coordinate the setup of an end-to-end ODU2 connection, either between nodes S3 and S6, or between nodes S3 and S18, including the configuration of the adaptation functions on these edge nodes, and in particular whether the multi-function access link between R1 and S3 should operate as an STM-64 or as a 10GE physical link.

Assumptions used in this example, as well as the service scenarios of sections 4.3, include:

o the R1-S3 and R8-S18 access links will be multi-function access links, which can be configured as an OTU2 trail or as an STM-64 or a 10GE physical link;

o the R3-S6 access link will be a multi-function access link which can be configured as an OTU2 trail or as an STM-64 physical link;

o the R4-S6 access link is pre-provisioned as an STM-64 physical link;

o all the other access links (and, in particular, the R2-S6 access links) are pre-provisioned as 10GE physical links, up to the MAC layer.

4.5. Protection and Restoration Configuration

As described in [RFC4427], recovery can be performed by either protection switching or restoration mechanisms. This section describes only services which are protected with linear protection, considering both end-to-end and segment protection, as defined in [ITU-T G.808.1] and [RFC4427]. The description of services using dynamic restoration is outside the scope of this document.

The MDSC needs to be capable of determining the network configurations to request different PNCs to coordinate the protection switching configuration to support protected connectivity services described in section 4.3.

In the service examples described in section 4.3, switching within the transport network domain is only performed at the OTN ODU layer. Therefore, it is also assumed that protection switching within the transport network also occurs at the OTN ODU layer, using the mechanisms defined in [ITU-T G.873.1].

4.5.1. Linear Protection (end-to-end)

To protect the connectivity services described in section 4.3 from failures within the OTN multi-domain transport network, the MDSC can decide to request its underlying PNCs to configure ODU2 linear protection between the transport network edge nodes (e.g., nodes S3 and S18 for the services setup between R1 and R8).

It is assumed that the OTN linear protection is configured as 1+1 unidirectional protection switching type according to the definition in [ITU-T G.808.1] and [ITU-T G.873.1], as well as in [RFC4427].

In these scenarios, a working transport entity and a protection transport entity, as defined in [ITU-T G.808.1], (or a working LSP and a protection LSP, as defined in [RFC4427]) should be configured in the data plane.

Two cases can be considered:

- In one case, the working and protection transport entities pass through the same PNC domains:

Working transport entity:	S3, S1, S2, S31, S33, S34, S15, S18
Protection transport entity:	S3, S4, S8, S32, S12, S17, S18

- In another case, the working and protection transport entities can pass through different PNC domains:

Working transport entity:	S3, S5, S7, S11, S12, S17, S18

```
      Protection transport entity:  S3, S1, S2,
                                    S31, S33, S34,
                                    S15, S18
```

The PNCs should be capable of reporting to the MDSC which is the active transport entity, as defined in [ITU-T G.808.1], in the data plane.

Given the fast dynamic of protection switching operations in the data plane (e.g., 50ms switching time), this reporting is not expected to be in real-time.

It is also worth noting that with unidirectional protection switching, e.g., 1+1 unidirectional protection switching, the active transport entity may be different in the two directions.

4.5.2. Segmented Protection

To protect the connectivity services defined in section 4.3 from failures within the OTN multi-domain transport network, the MDSC can decide to request its underlying PNCs to configure ODU2 linear protection between the edge nodes of each domain.

For example, MDSC can request PNC1 to configure linear protection between its edge nodes S3 and S2:

```
   Working transport entity:     S3, S1, S2

   Protection transport entity:  S3, S4, S8, S2
```

MDSC can also request PNC2 to configure linear protection between its edge nodes S15 and S18:

```
   Working transport entity:     S15, S18

   Protection transport entity:  S15, S12, S17, S18
```

MDSC can also request PNC3 to configure linear protection between its edge nodes S31 and S34:

```
   Working transport entity:     S31, S33, S34

   Protection transport entity:  S31, S32, S34
```

4.6. Notification

To realize the topology update, service update and restoration function, following notification types should be supported:

1. Object create

2. Object delete

3. Object state change

4. Alarm

There are three types of topology abstraction types defined in section 4.2, and the notifications should also be abstracted. The PNC and MDSC should coordinate together to determine the notification policy. This will include information such as when an intra-domain alarm occurred. The PNC may not report the alarm, but it should provide notification of the service state change to the MDSC.

Analysis and methods of how event alarms are triggered, managed and propagated are outside the scope of this document.

4.7. Path Computation with Constraints

It is possible to define constraints to be taken into account during path computation procedures (e.g., IRO/XRO).

For example, the CNC can request, at the CMI, an ODU transit service, as described in section 4.3.1, between R1 and R8 with the constraint to pass through the link from S2 to S31 (IRO), such that a qualified path could be:

```
R1 [(PKT) -> ODU2], S3 [(ODU2]), S1 [(ODU2]), S2 [(ODU2]),
S31 [(ODU2)], S33 [(ODU2)], S34 [(ODU2)],
S15 [(ODU2)], S18 [(ODU2)], R8 [ODU2 -> (PKT)]
```

If the CNC instead requested to pass through the link from S8 to S12, then the above path would not be qualified, while the following would be:

```
      R1 [(PKT) -> ODU2], S3[(ODU2]), S1 [(ODU2]), S2[(ODU2]),
      S8 [(ODU2]), S12[(ODU2]), S15 [(ODU2]), S18[(ODU2]), R8 [ODU2 ->
      (PKT)]
```

The mechanisms, used by the CNC to provide path constraints at the CMI, are outside the scope of this document. It is assumed that the MDSC can satisfy these constraints and take them into account in its path computation procedures (which would decide at least which domains and inter-domain links) and in the path computation constraints to provide to its underlying PNCs, to be taken into account in the path computation procedures implemented by the PNCs (with a more detailed view of topology).

Further detailed analysis is outside the scope of this document.

5. YANG Model Analysis

This section analyses how the IETF YANG models can be used at the MPIs, between the MDSC and the PNCs, to support the scenarios described in section 4.

The YANG models described in [ACTN-YANG] are assumed to be used at the MPI.

Section 5.1 describes the different topology abstractions provided to the MDSC by each PNC via its own MPI.

Section 5.2 describes how the MDSC can request different PNCs, via their own MPIs, the network configuration needed to setup the different services described in section 4.3.

Section 5.3 describes how the protection scenarios can be deployed, including end-to-end protection and segment protection, for both intra-domain and inter-domain scenario.

5.1. YANG Models for Topology Abstraction

This section analyses how each PNC can report its respective abstract topology to the MDSC, as described in section 4.2, using the Topology YANG models, defined in [RFC8345], with the TE Topology YANG augmentations, provided in [TE-TOPO], and the OTN technology-specific YANG augmentations, defined in [OTN-TOPO] or the Ethernet client technology-specific YANG augmentations, defined in [CLIENT-TOPO].

As described in section 4.1, the OTU4 trails on inter-domain and intra-domain physical links are pre-provisioned and therefore not exposed at the MPIs. Only the TE Links they support can be exposed at the MPI, depending on the topology abstraction performed by the PNC.

The access links can be multi-function access links, as described in section 4.4.

As described in section 4.1, each physical access link has a dedicated set of ODU termination and adaptation resources.

The [OTN-TOPO] model allows reporting within the OTN abstract topology also the access links which are capable of supporting the transparent client layers, defined in section 4.3.3 and in [CLIENT-SIGNAL]. These links can also be multi-function access links that can be configured as a transparent client physical links (e.g., STM-64 physical link) or as an OTUk trail.

In order to support the EPL and EVPL services, described in sections 4.3.2 and 4.3.4, the access links, which are capable of being configured as Ethernet physical links, are reported by each PNC within its respective Ethernet abstract topology, using the Topology YANG models, defined in [RFC8345], with the TE Topology YANG augmentations, defined in [TE-TOPO], and the Ethernet client technology-specific YANG augmentations, defined in [CLIENT-TOPO]. These links can also be multi-function access links that can be configured as an Ethernet physical link, an OTUk trail, or as a transparent client physical links (e.g., STM-64 physical link). In this case, these physical access links are represented in both the OTN and Ethernet abstract topologies.

The PNC reports the capabilities of the access or inter-domain link ends it can control. It is the MDSC responsibility to request configuration of these links matching the capabilities of both link ends.

It is worth noting that in the network scenarios analyzed in this document (where switching is performed only at the ODU layer), the Ethernet abstract topologies reported by the PNCs describes only the Ethernet client access links: no Ethernet TE switching capabilities are reported in these Ethernet abstract topologies, to report that the underlying networt domain is not capable to support Ethernet TE Tunnels/LSPs.

5.1.1. Domain 1 Black Topology Abstraction

PNC1 provides the required black topology abstraction, as described in section 4.2. It exposes at MPI1 to the MDSC, two TE Topology instances with only one TE node each.

The first TE Topology instance reports the domain 1 OTN abstract topology view (MPI1 OTN Topology), using the OTN technology-specific augmentations [OTN-TOPO], with only one abstract TE node (i.e., AN1) moreover, only inter-domain and access abstract TE links (which represent the inter-domain physical links and the access physical links which can support ODU, or transparent client layers, both), as shown in Figure 3 below.

```
                   ...................................
                   :                                 :
                   :       +-----------------+       :
                   :       |                 |       :
           (R1)- - --------|                 |-------- - -(S31)
                   : AN1-1 |                 | AN1-7 :
                   :       |                 |       :
           (R3)- - --------|                 |       :
                   : AN1-2 |       AN1       |       :
                   :       |                 |       :
           (R4)- - --------|                 |-------- - -(S32)
                   : AN1-3 |                 | AN1-6 :
                   :       |                 |       :
                   :       +-----------------+       :
                   :          |          |           :
                   :    AN1-4 |          | AN1-5     :
                   :..........|..........|...........:

                              |          |
                            (S11)      (S12)
```

Figure 3 - OTN Abstract Topology exposed at MPI1 (MPI1 OTN Topology)

The second TE Topology instance reports the domain 1 Ethernet abstract topology view (MPI1 ETH Topology), using the Ethernet technology-specific augmentations [CLIENT-TOPO], with only one abstract TE node (i.e., AN1) and only access abstract TE links (which represent the access physical links which can support Ethernet client layers), as shown in Figure 4 below.

```
                   ...................................
                   :                                 :
                   :       +-----------------+       :
                   :       |                 |       :
           (R1)- - --------|                 |       :
                   : AN1-1 |                 |       :
                   :       |                 |       :
           (R2)- - --------|                 |       :
                   : AN1-8 |       AN1       |       :
                   :       |                 |       :
                   :       |                 |       :
                   :       |                 |       :
                   :       |                 |       :
                   :       +-----------------+       :
                   :                                 :
                   :.................................:
```

Figure 4 - ETH Abstract Topology exposed at MPI1 (MPI1 ETH Topology)

The OTU4 trails on the inter-domain physical links (e.g., the link between S2 and S31) are pre-provisioned and exposed as external TE Links, within the MPI1 OTN topology (e.g., the external TE Link terminating on AN1-7 TE Link Termination Point (LTP) abstracting the OTU4 trail between S2 and S31).

The PNC1 exports at MPI1 the following external TE Links, within the MPI1 OTN topology, representing the multi-function access links under its control:

o two abstract TE Links, terminating on LTP AN1-1 and AN1-2 respectively, abstracting the physical access link between S3 and R1 and the access link between S6 and R3 respectively, reporting that they can support STM-64 client signals as well as ODU2 connections;

o one abstract TE Link, terminating on LTP AN1-3, abstracting the physical access link between S6 and R4, reporting that it can support STM-64 client signals but no ODU2 connections.

The information about the 10GE access link between S6 and R2 as well as the fact that the access link between S3 and R1 can also be configured as a 10GE link cannot be exposed by PNC1 within the MPI1 OTN topology.

Therefore, PNC1 exports at MPI1, within the MPI1 ETH topology, two abstract TE Links, terminating on LTP AN1-1 and AN1-8 respectively, abstracting the physical access link between S3 and R1 and the access link between S6 and R2 respectively, reporting that they can support Ethernet client signal with port-based and VLAN-based classifications.

PNC1 should expose at MPI1 also the ODU termination and adaptation resources which are available to carry client signals (e.g., Ethernet or STM-N) over OTN. This information is reported by the Tunnel Termination Points (TTPs) within the MPI1 OTN Topology.

In particular, PNC1 will report, within the MPI1 OTN Topology, one TTP for each access link (i.e., AN1-1, AN1-2, AN1-3 and AN1-8) and will assign a transition link or an inter-layer lock identifier, which is unique across all the TE Topologies PNC1 is exposing at MPI1, to each TTP and access link's LTP pair.

For simplicity purposes, this document assigns the same number to the LTP-ID, TTP-ID and ILL-ID that corresponds to the same access link (i.e., 1, 2, 3 and 8 respectively for the LTP, TTP and Inter-Layer Lock (IIL) corresponding with the access links AN1-1, AN1-2, AN1-3 and AN1-8).

The PNC1 native topology would represent the physical network topology of the domain controlled by the PNC, as shown in Figure 5.

```
                  ..................................
                  :                                :
                  :     Physical Topology @ PNC1   :
                  :                                :
                  :        +----+        +----+    :
                  :        |    |S1-1    |    |S2-3:
                  :        | S1 |--------| S2 |----- - -(S31)
                  :        +----+    S2-1+----+    :
                  :     S1-2/               |S2-2  :
                  :    S3-4/                |      :
                  :    +----+   +----+      |      :
                  :    |    |3 1|    |      |      :
          (R1)- - -----| S3 |---| S4 |      |      :
                  :S3-1+----+   +----+      |      :
                  :   S3-2 \        \S4-2   |      :
                  :         \S5-1    \      |      :
                  :        +----+     \     |      :
                  :        |    |      \S8-2|      :
                  :        | S5 |       \   |      :
                  :        +----+        \  |S8-1  :
          (R2)- - ------  2/    \3        \ |      :
                  :S6-1 \ /5     \1        \|      :
                  :    +----+   +----+   +----+    :
                  :    |    |   |    |   |    |S8-5:
          (R3)- - -----| S6 |---| S7 |---| S8 |----- - -(S32)
                  :S6-2+----+4 2+----+4 3+----+    :
                  :     /         |        |       :
          (R3)- - ------     S7-3 |        | S8-4  :
                  :S6-3           |        |       :
                  :...............|........|.......:

                                  |        |
                                (S11)    (S12)
```

Figure 5 - Physical Topology controlled by PNC1

The PNC1 native topology is not exposed and therefore it under PNC responsibility to abstract the whole domain physical topology as a single TE node and to maintain a mapping between the LTPs exposed at MPI abstract topologies and the associated physical interfaces controlled by the PNC:

Physical Interface	OTN Topology LTP	ETH Topology LTP
(Figure 5)	(Figure 3)	(Figure 4)
S2-3	AN1-7	
S3-1	AN1-1	AN1-1
S6-1		AN1-8
S6-2	AN1-2	
S6-3	AN1-3	
S7-3	AN1-4	
S8-4	AN1-5	
S8-5	AN1-6	

Appendix B.1.1 provides the detailed JSON code example ("mpi1-otn-topology.json") describing how the MPI1 ODU Topology is reported by the PNC1, using the [RFC8345], [TE-TOPO] and [OTN-TOPO] YANG models, at MPI1.

Appendix B.1.2 provides the detailed JSON code example ("mpi1-eth-topology.json") describing how the MPI1 ETH Topology is reported by the PNC1, using the [RFC8345], [TE-TOPO] and [CLIENT-TOPO] YANG models, at MPI1.

It is worth noting that this JSON code example does not provide all the attributes defined in the relevant YANG models, including:

- YANG attributes which are outside the scope of this document are not shown;

- The attributes describing the set of label values that are available at the inter-domain links (label-restriction container) are also not shown to simplify the JSON code example;

- The comments describing the rationale for not including some attributes in this JSON code example even if in the scope of this document are identified with the prefix "// __COMMENT" and included only in the first object instance (e.g., in the Access Link from the AN1-1 description or in the AN1-1 LTP description).

5.1.2. Domain 2 Black Topology Abstraction

PNC2 provides the required black topology abstraction, as described in section 4.2, to expose to the MDSC, at MPI2, two TE Topology instances with only one TE node each:

- the first instance reports the domain 2 OTN abstract topology view (MPI2 OTN Topology), with only one abstract node (i.e., AN2) and only inter-domain and access abstract TE links (which represent the inter-domain physical links and the access physical links which can support ODU, or transparent client layers or both);

- the instance reports the domain 2 Ethernet abstract topology view (MPI2 ETH Topology), with only one abstract TE node (i.e., AN2) and only access abstract TE links (which represent the access physical links which can support Ethernet client layers).

PNC2 also reports the ODU termination and adaptation resources which are available to carry client signals (e.g., Ethernet or STM-N) over OTN in the TTPs within the MPI2 OTN Topology.

In particular, PNC2 reports in both the MPI2 OTN Topology and MPI2 ETH Topology an AN2-1 access link which abstracts the multi-function physical access link between S18 and R8, which is assumed to correspond to the S18-3 LTP, within the PNC2 native topology. It also reports in the MPI2 ETH Topology a TTP which abstracts the ODU termination and adaptation resources dedicated to this physical access link and the inter-layer lock between this TTP, and the AN2-1 LTPs reported within the MPI2 OTN Topology and the MPI2 ETH Topology.

5.1.3. Domain 3 White Topology Abstraction

PNC3 provides the required white topology abstraction, as described in section 4.2, to expose to the MDSC, at MPI3, two TE Topology instances with multiple TE nodes, one for each physical node:

- the first instance reports the domain 3 OTN topology view (MPI3 OTN Topology), with four TE nodes, which represent the four physical nodes (i.e. S31, S32, S33 and S34), and abstract TE links, which represent the inter-domain and internal physical links;

- the second instance reports the domain 3 Ethernet abstract topology view (MPI3 ETH Topology), with only two TE nodes, which represent the two edge physical nodes (i.e., S31 and S33) and only the two access TE links which represent the access physical links.

PNC3 also reports the ODU termination and adaptation resources which are available to carry client signals (e.g., Ethernet or STM-N) over OTN in the TTPs within the MPI3 OTN Topology.

5.1.4. Multi-domain Topology Merging

MDSC does not have any knowledge of the topologies of each domain until each PNC reports its own abstract topologies, so the MDSC needs to merge these abstract topologies, provided by different PNCs, to build its own topology view of the multi-domain network (MDSC multi-domain native topology), as described in section 4.3 of [TE-TOPO].

The topology of each domain may be in an abstracted shape (refer to section 5.2 of [RFC8453] for a different level of abstraction), while the inter-domain link information must be complete and fully configured by the MDSC.

The inter-domain link information is reported to the MDSC by the two PNCs, controlling the two ends of the inter-domain link.

The MDSC needs to know how to merge these inter-domain links. One possibility is to use the plug-id information, defined in [TE-TOPO]: two inter-domain TE links, within two different MPI abstract topologies, terminating on two LTPs reporting the same plug-id value can be merged as a single intra-domain link, within any MDSC native topology.

The value of the reported plug-id information can be either assigned by a central network authority and configured within the two PNC domains. Alternatively, it may be discovered using an automatic discovery mechanisms (e.g., LMP-based, as defined in [RFC6898]).

In case the plug-id values are assigned by a central authority, it is under the central authority responsibility to assign unique values.

In case the plug-id values are automatically discovered, the information discovered by the automatic discovery mechanisms needs to be encoded as a bit string within the plug-id value. This encoding is implementation-specific, but the encoding rules need to be consistent across all the PNCs.

In case of co-existence within the same network of multiple sources for the plug-id (e.g., central authority and automatic discovery or even different automatic discovery mechanisms), it is needed that the plug-id namespace is partitioned to avoid that different sources assign the same plug-id value to different inter-domain links. Also, the encoding of the plug-id namespace within the plug-id value is implementation specific and will need to be consistent across all the PNCs.

This document assumes that the plug-id is assigned by a central authority, with the first octet set to 0x00 to represent the central authority namespace. The configuration method used, within each PNC domain, are outside the scope of this document.

For example, this document assumes that the following plug-id values are assigned, by administrative configuration, to the inter-domain links shown in Figure 1:

Inter-Domain Link	Plug-ID Value
S2-S31	0x000231
S7-S11	0x000711
S8-S12	0x000812
S8-S32	0x000832
S12-S32	0x001232
S15-S34	0x001534

Based on the plug-id values, the MDSC can merge the abstract topologies exposed by the underlying PNCs, as described in sections 5.1.1, 5.1.2 and 5.1.3 above, into its multi-domain native TE topology, as shown in Figure 6.

```
                ........................
                :                      :
                :   Network domain 1   :   .............
                :   Black Topology     :   :           :
                :     Abstraction      :   :  Network  :
                : AN1-1                :   :  domain 3 :
        (R1)- - ----------+            :   :  (White)  :
                :          \   +--------------+        :
        (R2)- - ---------+ +  /        :   :   \       :
                :         \| /         :   :    \      :
        (R3)- - --------- AN1 --+      :   :    S31 ---- - (R5)
                :         /|\    \     :   :   /   \   :   :
        (R4)- - ---------+ | \    +--------- S32   S33 - - (R6)
                :          |  \        :   :/  \   /   :
                :          |   +---+   :   /    S34    :
                :..........|.......|...:  /:   /       :
                           |       |     / :../........:
                           |       |    /    /
                ...........|.......|.../..../....
                :          |       |  /    /    :
                : Network  |       + /    /     :
                : domain 2 |      / /    /      :
                :          |     / /    /       :
                :          |    + / +--+        :
                :          |    |/ /            :
                : Black    +--- AN2 ------------- - -(R7)
                : Topology      | |     AN2-1   :
                : Abstraction   | +-------------- - -(R8)
                :               |               :
                :               +---------------- - -(R9)
                :                               :
                :...............................:
```

Figure 6 - Multi-domain Abstract Topology controlled by an MDSC

5.2. YANG Models for Service Configuration

This section analyses how the MDSC can request the different PNCs to setup different multi-domains services, as described in section 4.3, using the TE Tunnel YANG model, defined in [TE-TUNNEL], with the OTN technology-specific augmentations, defined in [OTN-TUNNEL] with the client service YANG model defined in [CLIENT-SIGNAL].

The service configuration procedure is assumed to be initiated (step 1 in Figure 7) at the CMI from CNC to MDSC. Analysis of the CMI models is (e.g., L1CSM, L2SM, VN) is outside the scope of this document, but it is assumed that the CMI YANG models provide all the information that allows the MDSC to understand that it needs to coordinate the setup of a multi-domain ODU data plane connection (which can be either an end-to-end connection or a segment connection) and, when needed, also the configuration of the adaptation functions in the edge nodes belonging to different domains.

```
                                 |
                                 | {1}
                                 V
                          ----------------
                         |           {2}  |
                         | {3}  MDSC      |
                         |                |
                          ----------------
                           ^     ^      ^
                    {3.1}  |     |      |
                 +---------+     |{3.2} |
                 |               |      +----------+
                 |               V                 |
                 |           ----------            |{3.3}
                 |          |   PNC2   |           |
                 |           ----------            |
                 |               ^                 |
                 V               | {4.2}           |
             ----------          V                 |
            |   PNC1   |       -----               V
             ----------      (Network)        ----------
                 ^          ( Domain 2)      |   PNC3   |
                 | {4.1}   (          _)      ----------
                 V          (        )            ^
               -----       C==========D           | {4.3}
             (Network)    /  (       ) \          V
            ( Domain 1)  /     -----    \       -----
           (           )/                \    (Network)
           A===========B                  \  ( Domain 3)
          / (         )                    \(           )
      AP-1   (       )                      X===========Z
               -----                         (         ) \
                                              (       )   AP-2
                                                -----
```

Figure 7 - Multi-domain Service Setup

As an example, the objective in this section is to configure a connectivity service between R1 and R8, such as one of the services described in section 4.3. The inter-domain path is assumed to be R1 <-> S3 <-> S1 <-> S2 <-> S31 <-> S33 <-> S34 <->S15 <-> S18 <-> R8 (see the physical topology in Figure 1).

According to the different client signal types, different adaptations can be required to be configured at the edge nodes (i.e., S3 and S18).

After receiving such request, MDSC determines the domain sequence, i.e., domain 1 <-> domain 3 <-> domain 2, with corresponding PNCs and the inter-domain links (step 2 in Figure 7).

As described in [PATH-COMPUTE], the domain sequence can be determined by running the MDSC own path computation on the MDSC native topology, defined in section 5.1.4, if and only if the MDSC has enough topology information. Otherwise, the MDSC can send path computation requests to the different PNCs (steps 2.1, 2.2 and 2.3 in Figure 7) and use this information to determine the optimal path on its internal topology and therefore the domain sequence.

The MDSC will then decompose the tunnel request into a few TE tunnel segments and request different PNCs to setup each intra-domain TE tunnel segment (steps 3, 3.1, 3.2 and 3.3 in Figure 7).

The MDSC will take care of the configuration of both the intra-domain TE tunnel segments and inter-domain TE tunnel hand-off via corresponding MPI (using the TE tunnel YANG model defined in [TE-TUNNEL] and the OTN tunnel YANG model augmentations defined in [OTN-TUNNEL]) through all the PNCs controlling the domains selected during path computation. More specifically, for the inter-domain TE tunnel hand-off, taking into account that the inter-domain links are all OTN links, the list of timeslots and the TPN value assigned to that ODUk connection at the inter-domain link needs to be configured by the MDSC.

The configuration of the timeslots and the TPN value used by the ODU2 connection on the internal links within a PNC domain (i.e., on the internal links within domain1) is outside the scope of this document, since it is a matter of the PNC domain internal implementation.

However, the configuration of the timeslots used by the ODU2 connection at the transport network domain boundaries (e.g., on the inter-domain links) needs to take into account the timeslots available on physical nodes belonging to different PNC domains (e.g., on node S2 within PNC1 domain and node S31 within PNC3 domain). Each PNC provides to the MDSC, at the MPI, the list of available timeslots on the inter-domain links using the TE Topology

YANG model and OTN Topology augmentation. The TE Topology YANG model in [TE-TOPO] is being updated to report the label set information. See section 1.7 of [TE-TUTORIAL] for more details.

The MDSC, when coordinating the setup of a multi-domain ODU connection, also configures the data plane resources (i.e., the list of timeslots and the TPN) to be used on the inter-domain links. The MDSC can know the timeslots which are available on the physical OTN nodes terminating the inter-domain links (e.g., S2 and S31) from the OTN Topology information exposed, at the MPIs, by the PNCs controlling the OTN physical nodes (e.g., PNC1 and PNC3 controlling the physical nodes S2 and S31 respectively).

In any case, the access link configuration is done only on the PNCs that control the access links (e.g., PNC-1 and PNC-3) and not on the PNCs of transit domain(s) (e.g., PNC-2). An access link will be configured by MDSC after the OTN tunnel is set up.

Access configuration will vary and will be dependent on each type of service. Further discussion and examples are provided in the following sub-sections.

5.2.1. ODU Transit Service

In this scenario, described in section 4.3.1, the physical access links are configured as 10G OTN links and, as described in section 5.1, reported by each PNC as TE Links within the OTN abstract topologies they expose to the MDSC.

When an IP link, between R1 and R8 is needed, the CNC requests, at the CMI, the MDSC to setup an ODU transit service.

From its native topology, shown in Figure 6, the MDSC understands, by means which are outside the scope of this document, that R1 is attached to the access link terminating on AN1-1 LTP in the MPI1 OTN Abstract Topology (Figure 3), exposed by PNC1, and that R8 is attached to the access link terminating on AN2-1 LTP in the MPI2 Abstract Topology, exposed by PNC2.

MDSC then performs multi-domain path computation (step 2 in Figure 7) and requests PNC1, PNC2 and PNC3, at MPI1, MPI2 and MPI3 respectively, to setup ODU2 (Transit Segment) Tunnels within the OTN Abstract Topologies they expose (MPI1 OTN Abstract Topology, MPI2 OTN Abstract Topology and MPI3 OTN Abstract Topology, respectively).

MDSC requests, at MPI1, PNC1 to setup an ODU2 (Transit Segment) Tunnel with one primary path between AN-1 and AN1-7 LTPs, within the MPI1 OTN Abstract Topology (Figure 4), using the TE Tunnel YANG model, defined in [TE-TUNNEL], with the OTN technology-specific augmentations, defined in [OTN-TUNNEL]:

- Source and Destination TTPs are not specified (since it is a Transit Tunnel): i.e., the source, src-tp-id, destination and dst-tp-id attributes of the TE tunnel instance are empty

- Ingress and egress points are indicated in the route-object-include-exclude list of the explicit-route-objects of the primary path:

  - The first element references the access link terminating on AN1-1 LTP

  - The last two element reference respectively the inter-domain link terminating on AN1-7 LTP and the data plane resources (i.e., the list of timeslots and the TPN) used by the ODU2 connection over that link.

Appendix B.2.1 provides the detailed JSON code ("mpi1-odu2-service-config.json") describing how the setup of this ODU2 (Transit Segment) Tunnel can be requested by the MDSC, using the [TE-TUNNEL] and [OTN-TUNNEL] YANG models at MPI1.

PNC1 knows, as described in the mapping table in Section 5.1.1, that AN-1 and AN1-7 LTPs within the MPI1 OTN Abstract Topology it exposes at MPI1 correspond to the S3-1 and S2-3 LTPs, respectively, within its native topology. Therefore it performs path computation, for an ODU2 connection between these LTPs within its native topology, and sets up the ODU2 cross-connections within the physical nodes S3, S1 and S2.

Since the R1-S3 access link is a multi-function access link, PNC1 also configures the OTU2 trail before setting up the ODU2 cross-connection in node S3.

As part of the OUD2 cross-connection configuration in node S2, PNC1 configures the data plane resources (i.e., the list of timeslots and the TPN), to be used by this ODU2 connection on the S2-S31 inter-domain link, as requested by the MDSC.

Following similar requests from MDSC to setup ODU2 (Transit Segment) Tunnels within the OTN Abstract Topologies they expose, PNC2 then sets up ODU2 cross-connections on nodes S31 and S33 while PNC3 sets up ODU2 cross-connections on nodes S15 and S18. PNC2 also configures the OTU2 trail on the S18-R8 multi-function access link.

5.2.1.1. Single Domain Example

To setup an ODU2 end-to-end connection, supporting an IP link, between R1 and R3, the CNC requests, at the CMI, the MDSC to setup an ODU transit service.

Following the procedures described in section 5.2.1, MDSC requests only PCN1 to setup the ODU2 (Transit Segment) Tunnel between the access links terminating on AN-1 and AN1-2 LTPs within the MPI1 Abstract Topology and PNC1 sets up ODU2 cross-connections on nodes S3, S5 and S6. PNC1 also configures the OTU2 trails on the R1-S3 and R3-S6 multi-function access links.

5.2.2. EPL over ODU Service

In this scenario, described in section 4.3.2, the access links are configured as 10GE Links and, as described in section 5.1, reported by each PNC as TE Links within the ETH abstract topologies they expose to the MDSC.

When this IP link, between R1 and R8, is needed, the CNC requests, at the CMI, the MDSC to setup an EPL service.

From its native topology, shown in Figure 6, the MDSC understands, by means which are outside the scope of this document, that R1 is attached to the access link terminating on AN1-1 LTP in the MPI1 ETH Abstract Topology, exposed by PNC1, and that R8 is attached to the access link terminating on AN2-1 LTP in the MPI2 ETH Abstract Topology, exposed by PNC2.

As described in sections 5.1.1 and 5.1.2:

o the AN1-1 LTP, within the MPI1 ETH Abstract Topology, and the AN1-1 TTP, within the MPI1 OTN Abstract Topology, have the same IIL identifier (within the scope of MPI1);

- the AN2-1 LTP, within the MPI2 ETH Abstract Topology, and the AN2-1 TTP, within the MPI2 OTN Abstract Topology, have the same IIL identifier (within the scope of MPI2).

Therefore, the MDSC also understands that it needs to coordinate the setup of a multi-domain ODU2 Tunnel between AN1-1 and AN2-1 TTPs, abstracting S3-1 and S18-3 TTPs, within the OTN Abstract Topologies exposed by PNC1 and PNC2, respectively.

MDSC then performs multi-domain path computation (step 2 in Figure 7) and then requests:

- PNC1, at MPI1, to setup an ODU2 (Head Segment) Tunnel within the MPI1 OTN Abstract Topology;

- PNC1, at MPI1, to steer the Ethernet client traffic from/to AN1-1 LTP, within the MPI1 ETH Abstract Topology, thought that ODU2 (Head Segment) Tunnel;

- PNC3, at MPI3, to setup an ODU2 (Transit Segment) Tunnel within the MPI3 OTN Abstract Topology;

- PNC2, at MPI2, to setup ODU2 (Tail Segment) Tunnel within the MPI2 OTN Abstract Topology;

- PNC2, at MPI2, to steer the Ethernet client traffic to/from AN2-1 LTP, within the MPI2 ETH Abstract Topology, through that ODU2 (Tail Segment) Tunnel.

MDSC requests, at MPI1, PNC1 to setup an ODU2 (Head Segment) Tunnel with one primary path between the AN1-1 TTP and AN1-7 LTP, within the MPI1 OTN Abstract Topology (Figure 4), using the TE Tunnel YANG model, defined in [TE-TUNNEL], with the OTN technology-specific augmentations, defined in [OTN-TUNNEL]:

- Only the Source TTP (i.e., AN1 TE-Node and AN1-1 TTP) is specified (since it is a Head Segment Tunnel): therefore the Destination TTP is not specified

- The egress point in indicated in the route-object-include-exclude list of the explicit-route-objects of the primary path:

- o The last two element reference respectively the inter-domain link terminating on AN1-7 LTP and the data plane resources (i.e., the list of timeslots and the TPN) used by the ODU2 connection over that link.

Appendix B.2.2 provides the detailed JSON code ("mpi1-odu2-tunnel-config.json") describing how the setup of this ODU2 (Head Segment) Tunnel can be requested by the MDSC, using the [TE-TUNNEL] and [OTN-TUNNEL] YANG models at MPI1.

MDSC requests, at MPI1, PNC1 to steer the Ethernet client traffic from/to AN1-2 LTP, within the MPI1 ETH Abstract Topology (Figure 4), thought the MPI1 ODU2 (Head Segment) Tunnel, using the Ethernet Client YANG model, defined in [CLIENT-SIGNAL].

Appendix Error! Reference source not found. provides the detailed JSON code ("mpi1-epl-service-config.json") describing how the setup of this EPL service using the ODU2 Tunnel can be requested by the MDSC, using the [CLIENT-SIGNAL] YANG model at MPI1.

PNC1 knows, as described in the table in section 5.1.1, that the AN1-1 TTP and the AN1-7 LTP, within the MPI1 OTN Abstract Topology it exposes at MPI1, correspond to S3-1 TTP and S2-3 LTP, respectively, within its native topology. Therefore it performs path computation, for an ODU2 connection between S3-1 TTP and S2-3 LTP within its native topology, and sets up the ODU2 cross-connections within the physical nodes S3, S1 and S2, as shown in section 4.3.2.

As part of the OUD2 cross-connection configuration in node S2, PNC1 configures the data plane resources (i.e., the list of timeslots and the TPN), to be used by this ODU2 connection on the S2-S31 inter-domain link, as requested by the MDSC.

After the configuration of the ODU2 cross-connection in node S3, PNC1 also configures the [ETH -> (ODU)] and [(ODU2) -> ETH] adaptation functions, within node S3, as shown in section 4.3.2.

Since the R1-S3 access link is a multi-function access link, PNC1 also configures the 10GE link before this step.

Following similar requests from MDSC to setup ODU2 (Segment) Tunnels within the OTN Abstract Topologies they expose as well as the steering of the Ethernet client traffic, PNC3 then sets up ODU2 cross-connections on nodes S31 and S33 while PNC2 sets up ODU2 cross-connections on nodes S15 and S18 as well as the [ETH -> (ODU2)] and [(ODU2) -> ETH] adaptation functions in node S18, as shown in section 4.3.2. PNC2 also configures the 10GE link on the S18-R8 multi-function access link.

5.2.2.1. Single Domain Example

When this IP link, between R1 and R2, is needed, the CNC requests, at the CMI, the MDSC to setup an EPL service.

Following the procedures described in section 5.2.2, the MDSC requests PCN1 to:

- Setup an ODU2 (end-to-end) Tunnel between the AN1-1 and AN1-2 TTPs, abstracting S3-1 and S6-1 TTPs, within the MPI1 OTN Abstract Topology exposed by PNC1 at MPI1;

- Steer the Ethernet client traffic between the AN1-1 and AN1-8 LTPs, exposed by PNC1 within MPI1 ETH Abstract Topology, through that ODU2 (end-to-end) Tunnel.

Then PNC1 sets up ODU2 cross-connections on nodes S3, S5 and S6 as well as the [ETH -> (ODU)] and [(ODU2) -> ETH] adaptation functions in nodes S3 and S6, as shown in section 4.3.2. PNC1 also configures the 10GE link on the R1-S3 multi-function access link (the R2-S6 access link has been pre-provisioned as a 10GE link, as described in section 4.4).

5.2.3. Other OTN Client Services

In this scenario, described in section 4.3.3, the access links are configured as STM-64 links and, as described in section 5.1, reported by each PNC as TE Links within the OTN Abstract Topologies they expose to the MDSC.

The CNC requests, at the CMI, MDSC to setup an STM-64 Private Line service between R1 and R8.

Following similar procedures as described in section 5.2.2, MDSC understands that:

- R1 is attached to the access link terminating on AN1-1 LTP in the MPI1 OTN Abstract Topology, exposed by PNC1, and that R8 is attached to the access link terminating on AN2-1 LTP in the MPI2 OTN Abstract Topology, exposed by PNC2;

- it needs to coordinate the setup of a multi-domain ODU2 Tunnel between the AN1-1 and AN2-1 TTPs, abstracting S3-1 and S18-3 TTPs, within the OTN Abstract Topologies exposed by PNC1 and PNC2, respectively.

The MDSC then performs multi-domain path computation (step 2 in Figure 7) and then requests:

- PNC1, at MPI1, to setup an ODU2 (Head Segment) Tunnel within the MPI1 OTN Abstract Topology;

- PNC1, at MPI1, to steer the STM-64 transparent client traffic from/to AN1-1 LTP, within the MPI1 OTN Abstract Topology, thought that ODU2 (Head Segment) Tunnel;

- PNC3, at MPI3, to setup an ODU2 (Transit Segment) Tunnel within the MPI3 OTN Abstract Topology;

- PNC2, at MPI2, to setup ODU2 (Tail Segment) Tunnel within the MPI2 OTN Abstract Topology;

- PNC2, at MPI2, to steer the STM-64 transparent client traffic to/from AN2-1 LTP, within the MPI2 ETH Abstract Topology, through that ODU2 (Tail Segment) Tunnel.

PNC1, PNC2 and PNC3 then sets up the ODU2 cross-connections within the physical nodes S3, S1, S2, S31, S33, S15 and S18 as well as the [STM-64 -> (ODU)] and [(ODU2) -> STM-64] adaptation functions in nodes S3 and S18, as shown in section 4.3.3. PNC1 and PNC2 also configure the STM-64 links on the R1-S3 and R8-S18 multi-function access links, respectively.

5.2.3.1. Single Domain Example

When this IP link, between R1 and R3, is needed, the CNC requests, at the CMI, the MDSC to setup an STM-64 Private Line service.

The MDSC and PNC1 follows similar procedures as described in section 5.2.2.1 to set up ODU2 cross-connections on nodes S3, S5 and S6 as well as the [STM-64 -> (ODU)] and [(ODU2) -> STM-64] adaptation functions in nodes S3 and S6, as shown in section 4.3.3. PNC1 also configures the STM-64 links on the R1-S3 and R3-S6 multi-function access links.

5.2.4. EVPL over ODU Service

In this scenario, described in section 4.3.4, the access links are configured as 10GE links, as described in section 5.2.2 above.

The CNC requests, at the CMI, the MDSC to setup two EVPL services: one between R1 and R2, and another between R1 and R8.

Following similar procedures as described in section 5.2.2 and 5.2.2.1, MDSC understands that:

- R1 and R2 are attached to the access links terminating respectively on AN1-1 and AN1-8 LTPs in the MPI1 ETH Abstract Topology, exposed by PNC1, and that R8 is attached to the access link terminating on AN2-1 LTP in the MPI2 ETH Abstract Topology, exposed by PNC2;

- To setup the first (single-domain) EVPL service, between R1 and R2, it needs to coordinate the setup of a single-domain ODU0 Tunnel between the AN1-1 and AN1-8 TTPs, abstracting S3-1 and S6-1 TTPs, within the OTN Abstract Topology exposed by PNC1;

- To setup the second (multi-domain) EPVL service, between R1 and R8, it needs to coordinate the setup of a multi-domain ODU0 Tunnel between the AN1-1 and AN2-1 TTPs, abstracting nodes S3-1 and S18-3 TTPs, within the OTN Abstract Topologies exposed by PNC1 and PNC2, respectively.

To setup the first (single-domain) EVPL service between R1 and R2, the MDSC and PNC1 follows similar procedures as described in section 5.2.2.1 to set up ODU0 cross-connections on nodes S3, S5 and S6 as well as the [VLAN -> (ODU0)] and [(ODU0) -> VLAN] adaptation functions, in nodes S3 and S6, as shown in section 4.3.4. PNC1 also configures the 10GE link on the R1-S3 multi-function access link.

As part of the [VLAN -> (ODU0)] and [(ODU0) -> VLAN] adaptation functions configurations in nodes S2 and S6, PNC1 configures also the classification rules required to associated only the Ethernet client traffic received with VLAN ID 10 on the R1-S3 and R2-S6 access links with this EVPL service. The MDSC provides this information to PNC1 using the [CLIENT-SIGNAL] model.

To setup the second (multi-domain) EVPL service between R1 and R8, the MDSC, PNC1, PNC2 and PNC3 follows similar procedures as described in section 5.2.2 to setup the ODU0 cross-connections within the physical nodes S3, S1, S2, S31, S33, S15 and S18 as well as the [VLAN -> (ODU0)] and [(ODU0) -> VLAN] adaptation functions in nodes S3 and S18, as shown in section 4.3.4. PNC2 also configures the 10GE link on the R8-S18 multi-function access link (the R1-S3 10GE link has been already configured when the first EVPL service has been setup).

As part of the [VLAN -> (ODU0)] and [(ODU0) -> VLAN] adaptation functions configurations in nodes S3 and S18, PNC1 and, respectively, PNC2 configure also the classification rules required to associated only the Ethernet client traffic received with VLAN ID 20 on the R1-S3 and R8-S18 access links with this EVPL service. The MDSC provides this information to PNC1 and PNC2 using the [CLIENT-SIGNAL] model.

5.3. YANG Models for Protection Configuration

5.3.1. Linear Protection (end-to-end)

As described in section 4.5.1, the MDSC can decide to protect a multi-domain connectivity service by setting up ODU linear protection switching between edge nodes controlled by different PNCs (e.g., nodes S3 and S8, controlled by PNC1 and PNC2 respectively, to protect services between R1 and R8).

MDSC performs path computation, as described in section 5.2, to compute both the paths for working and protection transport entities: the computed paths can pass through these same PNC domains or through different transit PNC domains.

Considering the case, described in section 4.5.1, where the working and protection transport entities pass through the same domain, MDSC would perform the same steps described in section 5.2 to setup the ODU Tunnel and to configure the steering of the client traffic between the access links and the ODU Tunnel. The only differences are in the configuration of the ODU Tunnels.

MDSC requests at the MPI1, PNC1 to setup an ODU2 (Head Segment) Tunnel within the MPI1 OTN Abstract Topology (Figure 4), using the TE Tunnel YANG model, defined in [TE-TUNNEL], with the OTN technology-specific augmentations, defined in [OTN-TUNNEL], with one primary path and one secondary path with1+1 protection switching enabled:

- Only the Source TTP (i.e., AN1-1 TTP) is specified (since it is a Head Segment Tunnel), as described in section 5.2.2;

- The egress point for the working transport entity in indicated in the route-object-include-exclude list of the explicit-route-objects of the primary path, as described in section 5.2.2;

- The protection switching end-point in indicated in the route-object-include-exclude list of the explicit-route-objects of the secondary path:

  - The first element references the TE-Node of the Source TTP (i.e., AN1 TE-Node);

- The egress point for the protection transport entity in indicated in the route-object-include-exclude list of the explicit-route-objects of the secondary path:

  - The last two element reference respectively the inter-domain link terminating on AN1-6 LTP and the data plane resources (i.e., the list of timeslots and the TPN) used by the ODU2 connection over that link.

PNC1 knows, as described in the table in section 5.1.1, that the AN1-1 TTP, AN1-7 LTP and the AN1-6 LTP, within the MPI1 OTN Abstract Topology it exposes at MPI1, correspond to S3-1 TTP, S2-3 LTP and the S8-5 LTP, respectively, within its native topology. It also understands, from the route-object-include-exclude list of the explicit-route-objects of the secondary path configuration (whose last two elements represent an inter-domain link), that node S3 is the end-point of the protection group while the other end-point is outside of its control domain.

PNC1 can performs path computation within its native topology and setup the ODU connections in nodes S3, S1, S2, S4 and S8 as well as configure the protection group in node S3.

5.3.2. Segmented Protection

Under specific policies, it is possible to deploy a segmented protection for multi-domain services. The configuration of the segmented protection can be divided into a few steps, considering the example in section 4.5.2, the following steps would be used.

MDSC performs path computation, as described in section 5.2, to compute all the paths for working and protection transport entities, which pass through the same PNC domains and inter-domain links: the MDSC would perform the same steps described in section 5.2 to setup the ODU Tunnel and to configure the steering of the client traffic between the access links and the ODU Tunnel. The only differences are in the configuration of the ODU Tunnels.

MDSC requests at the MPI1, PNC1 to setup an ODU2 (Head Segment) Tunnel within the MPI1 OTN Abstract Topology (Figure 4), using the TE Tunnel YANG model, defined in [TE-TUNNEL], with the OTN technology-specific augmentations, defined in [OTN-TUNNEL], with one primary path and one secondary path with 1+1 protection switching enabled:

- Only the Source TTP (i.e., AN1-1 TTP) is specified (since it is a Head Segment Tunnel), as described in section 5.2.2;

- The egress point (i.e., AN1-7 LTP) is indicated in the route-object-include-exclude list of the explicit-route-objects of the primary path, as described in section 5.2.2;

- The protection switching end-points are indicated in the route-object-include-exclude list of the explicit-route-objects of the secondary path:

  - The first element references the TE-Node of the Source TTP (i.e., AN1 TE-Node);

  - The last element references the TE-Node of the egress point (i.e., AN1 TE-Node).

As described in section 5.2.2, PNC1 knows that the AN1-1 TTP and the AN1-7 LTP, within the MPI1 OTN Abstract Topology it exposes at MPI1, correspond to S3-1 TTP and the S2-3 LTP, respectively, within its native topology. It also understands, from the route-object-include-exclude list of the explicit-route-objects of the secondary path configuration (whole last element represent an abstract node terminating the inter-domain link used for the primary path), that the protection group should be terminated in nodes S3 and S2.

PNC1 will perform path computations using its native topology and setup the ODU connections in nodes S3, S1, S2, S4 and S8 as well as configure the protection group in nodes S3 and S2.

Following similar requests from MDSC to setup ODU2 (Segment) Tunnels, with segment protection, within the OTN Abstract Topologies they expose. PNC3 then sets up ODU2 cross-connections on nodes S31, S32, S33 and S34 and segment protection between nodes S31 and D34. PNC2 sets up ODU2 cross-connections on nodes S15, S12, S17 and S18 and segment protection between nodes S15 and S18.

MDSC stitch the configuration above to form its internal view of the end-to-end tunnel with segmented protection.

Given the configuration above, the protection capability has been deployed on the tunnels. The head-end node of each domain can do the switching once there is a failure on one the tunnel segment. For example, in Network domain 1, when there is a failure on the S1-S2 lin, the head-end nodes S2 and S3 will automatically do the switching to S3-S4-S8-S2. This switching will be reported to the corresponding PNC (PNC1 in this example) and then MDSC. Other PNCs (PNC2 and PNC3 in this example) will not be aware of the failure and switching, nor do the nodes in Network domain 2 and 3.

5.4. Notifications

Notification mechanisms are required for the scenarios analyzed in this draft, as described in section 4.6.

The notification mechanisms are protocol-dependent. It is assumed that the RESTCONF protocol, defined in [RFC8040], is used at the MPIs mentioned in this document.

On the perspective of MPI, the MDSC is the client while the PNC is acting as the server of the notification. The essential event streams, subscription and processing rules after receiving notification can be found in section 6 of [RFC8040].

5.5. Path Computation with Constraints

The path computation constraints that can be supported at the MPI using the IETF YANG models defined in [TE-TUNNEL] and [PATH-COMPUTE].

When there is a technology-specific network (e.g., OTN), the corresponding technology (e.g., OTN) model should also be used to specify the tunnel information on MPI, with the constraint included in TE Tunnel model.

Further detailed analysis is outside the scope of this document

6. Security Considerations

This document analyses the applicability of the YANG models being defined by the IETF to support OTN single and multi-domain scenarios.

When deploying ACTN functional components the securing of external interfaces and hardening of resource datastores, the protection of confidential information, and limiting the access of function, should all be carefully considered. Section 9 of [RFC8453] highlights that implementations should consider encrypting data that flows between key components, especially when they are implemented at remote node. Further discussion on securing the interface between the MDSC and PNCs via the MDSC-PNC Interface (MPI) is discussed in section 9.2 of [RFC8453].

The YANG modules highlighted in this document are designed to be accessed via network configuration protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. When using NETCONF, utilizing a secure transport via Secure Shell (SSH) [RFC6242] is mandatory. If using RESTCONF, then secure transport via TLS [RFC8446] is mandatory. When using either NETCONF or RESTCONF, the use of Network Configuration Access Control Model (NACM) [RFC8341] may be used to restrict access to specific protocol operations and content.

6.1. OTN Security

Inherently OTN networks ensure privacy and security via hard partitioning of traffic onto dedicated circuits. The separation of network traffic makes it difficult to intercept data transferred between nodes over OTN-channelized links.

In OTN the (General Communication Channel) GCC is used for OAM functions such as performance monitoring, fault detection, and signaling. The GCC control channel should be secured using a suitable mechanism.

7. IANA Considerations

This document requires no IANA actions.

8. References

8.1. Normative References

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9. Acknowledgments

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Appendix A. Validating a JSON fragment against a YANG Model

The objective is to have a tool that allows validating whether a piece of JSON code embedded in an Internet-Draft is compliant with a YANG model without using a client/server.

A.1. Manipulation of JSON fragments

This section describes the various ways JSON fragments are used in the I-D processing and how to manage them.

Let's call "folded-JSON" the JSON embedded in the I-D: it fits the 72 chars width and it is acceptable for it to be invalid JSON.

We then define "unfolded-JSON" a valid JSON fragment having the same contents of the "folded-JSON " without folding, i.e. limits on the text width. The folding/unfolding operation may be done according to [RFC-FOLD]. The "unfolded-JSON" can be edited by the authors using JSON editors with the advantages of syntax validation and pretty-printing.

Both the "folded" and the "unfolded" JSON fragments can include comments having descriptive fields and directives we'll describe later to facilitate the reader and enable some automatic processing.

The presence of comments in the "unfolded-JSON" fragment makes it an invalid JSON encoding of YANG data. Therefore we call "naked JSON" the JSON where the comments have been stripped out: not only it is valid JSON but it is a valid JSON encoding of YANG data.

The following schema resumes these definitions:

```
                    unfold_it -->             stripper -->

          Folded-JSON           Unfolded-JSON             Naked JSON

                    <-- fold_it              <-- author edits

<=72-chars?    must              may                      may

valid JSON?     may             must                     must

JSON-encoding
of YANG data?   may              may                     must
```

Our validation toolchain has been designed to take a JSON in any of the three formats and validate it automatically against a set of relevant YANG modules using available open-source tools. It can be found at: https://github.com/GianmarcoBruno/json-yang/

A.2. Comments in JSON fragments

We found useful to introduce two kinds of comments, both defined as key-value pairs where the key starts with "//":

- free-form descriptive comments, e.g."// COMMENT" : "refine this" to describe properties of JSON fragments.

- machine-usable directives e.g. "// __REFERENCES__DRAFTS__" : { "ietf-routing-types@2017-12-04": "rfc8294",} which can be used to automatically download from the network the relevant I-Ds or RFCs and extract from them the YANG models of interest. This is particularly useful to keep consistency when the drafting work is rapidly evolving.

A.3. Validation of JSON fragments: DSDL-based approach

The idea is to generate a JSON driver file (JTOX) from YANG, then use it to translate JSON to XML and validate it against the DSDL schemas, as shown in Figure 8.

Useful link: https://github.com/mbj4668/pyang/wiki/XmlJson

```
                           (2)
               YANG-module ---> DSDL-schemas (RNG,SCH,DSRL)
                      |                  |
                      | (1)              |
                      |                  |
      Config/state  JTOX-file            | (4)
             \        |                  |
              \       |                  |
               \      V                  V
      JSON-file------------> XML-file ----------------> Output
                 (3)
```

Figure 8 - DSDL-based approach for JSON code validation

In order to allow the use of comments following the convention defined in section 3, without impacting the validation process, these comments will be automatically removed from the JSON-file that will be validate.

A.4. Validation of JSON fragments: why not using an XSD-based approach

This approach has been analyzed and discarded because no longer supported by pyang.

The idea is to convert YANG to XSD, JSON to XML and validate it against the XSD, as shown in Figure 9:

```
                     (1)
         YANG-module ---> XSD-schema - \       (3)
                                        +--> Validation
         JSON-file------> XML-file ----/
                     (2)
```

Figure 9 - XSD-based approach for JSON code validation

The pyang support for the XSD output format was deprecated in 1.5 and removed in 1.7.1. However pyang 1.7.1 is necessary to work with YANG 1.1 so the process shown in Figure 9 will stop just at step (1).

Appendix B. Detailed JSON Examples

The JSON code examples provided in this appendix have been validated using the tools in Appendix A and folded using the tool in [RFC-FOLD].

B.1. JSON Examples for Topology Abstractions

B.1.1. JSON Code: mpi1-otn-topology.json

This is the JSON code reporting the OTN Topology @ MPI1:

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

   {
     "// __LAST_UPDATE__": "October 21, 2019",
     "// __TITLE__": "ODU Black Topology @ MPI1",
     "// __REFERENCE_DRAFTS__": {
       "ietf-routing-types@2017-12-04": "rfc8294",
       "ietf-te-types@2019-07-05": "draft-ietf-teas-yang-te-types-10",
       "ietf-layer1-types@2019-09-09": "draft-ietf-ccamp-layer1-types-0\
   \2",
       "ietf-network@2018-02-26": "rfc8345",
       "ietf-network-topology@2018-02-26": "rfc8345",
       "ietf-te-topology@2019-02-07": "draft-ietf-teas-yang-te-topo-22",
       "ietf-otn-topology@2019-07-07": "draft-ietf-ccamp-otn-topo-yang-\
   \08"
     },
     "// __MISSING_ATTRIBUTES__": true,
     "ietf-network:networks": {
       "network": [
         {
           "network-id": "providerId/201/clientId/300/topologyId/otn-bl\
   \ack-topology",
           "network-types": {
             "ietf-te-topology:te-topology": {
               "ietf-otn-topology:otn-topology": {}
             }
           },
           "ietf-te-topology:te-topology-identifier": {
             "provider-id": 201,
             "client-id": 300,
             "topology-id": "otn-black-topology"
           },
           "// __COMMENT__ ietf-te-topology:te": "presence container re\
   \quires: provider-id, client-id and te-topology-id",
           "ietf-te-topology:te": {
             "name": "OTN Black Topology @ MPI1"
           },
           "ietf-network:node": [
             {
               "// __NODE__:__DESCRIPTION__": {
                 "name": "AN1",
                 "identifier": "10.0.0.1",
                 "type": "Abstract Node",
                 "physical node(s)": "The whole network domain 1"
               },
               "node-id": "10.0.0.1",
               "ietf-te-topology:te-node-id": "10.0.0.1",
               "ietf-te-topology:te": {
                 "te-node-attributes": {
                   "name": "AN11",
                   "is-abstract": "",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "tunnel-termination-point": [
                   {
                     "// __COMMENT__ tunnel-tp-id": "AN1-1 TTP-ID (1 ->\
   \ 0x01 -> 'AQ==')",
                     "tunnel-tp-id": "AQ==",
                     "name": "AN1-1 OTN TTP",
                     "// __COMMENT__ encoding and switching-capability"\
   \: "OTN (ODU)",
                     "switching-capability": "ietf-te-types:switching-o\
   \tn",
                     "encoding": "ietf-te-types:lsp-encoding-oduk",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-1 ILL\
   \-ID (1) }",
                     "inter-layer-lock-id": [
                       1
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   },
                   {
                     "// __COMMENT__ tunnel-tp-id": "AN1-2 TTP-ID (2 ->\
   \ 0x02 -> 'Ag==')",
                     "tunnel-tp-id": "Ag==",
                     "name": "AN1-2 OTN TTP",
                     "// __COMMENT__ encoding and switching-capability"\
   \: "OTN (ODU)",
                     "switching-capability": "ietf-te-types:switching-o\
   \tn",
                     "encoding": "ietf-te-types:lsp-encoding-oduk",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-2 ILL\
   \-ID (2) }",
                     "inter-layer-lock-id": [
                       2
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   },
                   {
                     "// __COMMENT__ tunnel-tp-id": "AN1-3 TTP-ID (3 ->\
   \ 0x03 -> 'Awo=')",
                     "tunnel-tp-id": "Awo=",
                     "name": "AN1-3 OTN TTP",
                     "// __COMMENT__ encoding and switching-capability"\
   \: "OTN (ODU)",
                     "switching-capability": "ietf-te-types:switching-o\
   \tn",
                     "encoding": "ietf-te-types:lsp-encoding-oduk",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-3 ILL\
   \-ID (3) }",
                     "inter-layer-lock-id": [
                       3
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   },
                   {
                     "// __COMMENT__ tunnel-tp-id": "AN1-8 TTP-ID (8 ->\
   \ 0x08 -> 'CA==')",
                     "tunnel-tp-id": "CA==",
                     "name": "AN1-8 OTN TTP",
                     "// __COMMENT__ encoding and switching-capability"\
   \: "OTN (ODU)",
                     "switching-capability": "ietf-te-types:switching-o\
   \tn",
                     "encoding": "ietf-te-types:lsp-encoding-oduk",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-8 ILL\
   \-ID (1) }",
                     "inter-layer-lock-id": [
                       8
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   }
                 ]
               },
               "ietf-network-topology:termination-point": [
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-1 LTP",
                     "link type(s)": "Multi-function (OTU2, STM-64 and \
   \10GE)",
                     "physical node": "S3",
                     "unnumberd/ifIndex": 1,
                     "port type": "tributary port",
                     "connected to": "R1"
                   },
                   "tp-id": "1",
                   "ietf-te-topology:te-tp-id": 1,
                   "ietf-te-topology:te": {
                     "name": "AN1-1 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU2"
                             }
                           }
                         ]
                       }
                     ],
                     "// __NOT-PRESENT__ inter-domain-plug-id": "Use of\
   \ plug-id for access Link is outside the scope of this document",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-1 ILL\
   \-ID (1) }",
                     "inter-layer-lock-id": [
                       1
                     ],
                     "admin-status": "up",
                     "oper-status": "up",
                     "ietf-otn-topology:client-svc": {
                       "client-facing": true,
                       "supported-client-signal": [
                         "ietf-layer1-types:STM-64"
                       ]
                     }
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-2 LTP",
                     "link type(s)": "Multi-function (OTU2 and STM-64)",
                     "physical node": "S6",
                     "unnumberd/ifIndex": 2,
                     "port type": "tributary port",
                     "connected to": "R3"
                   },
                   "tp-id": "2",
                   "ietf-te-topology:te-tp-id": 2,
                   "ietf-te-topology:te": {
                     "name": "AN1-2 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU2"
                             }
                           }
                         ]
                       }
                     ],
                     "// __NOT-PRESENT__ inter-domain-plug-id": "Use of\
   \ plug-id for access Link is outside the scope of this document",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-2 ILL\
   \-ID (2) }",
                     "inter-layer-lock-id": [
                       2
                     ],
                     "admin-status": "up",
                     "oper-status": "up",
                     "ietf-otn-topology:client-svc": {
                       "client-facing": true,
                       "supported-client-signal": [
                         "ietf-layer1-types:STM-64"
                       ]
                     }
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-3 LTP",
                     "link type(s)": "STM-64",
                     "physical node": "S6",
                     "unnumberd/ifIndex": 3,
                     "port type": "tributary port",
                     "connected to": "R4"
                   },
                   "tp-id": "3",
                   "ietf-te-topology:te-tp-id": 3,
                   "ietf-te-topology:te": {
                     "name": "AN1-3 LTP",
                     "// __NOT-PRESENT__ interface-switching-capability\
   \": "STM-64 Access Link only (no ODU switching)",
                     "// __NOT-PRESENT__ inter-domain-plug-id": "Use of\
   \ plug-id for access Link is outside the scope of this document",
                     "// __COMMENT__ inter-layer-lock-id": "{ AN1-3 ILL\
   \-ID (3) }",
                     "inter-layer-lock-id": [
                       3
                     ],
                     "admin-status": "up",
                     "oper-status": "up",
                     "ietf-otn-topology:client-svc": {
                       "client-facing": true,
                       "supported-client-signal": [
                         "ietf-layer1-types:STM-64"
                       ]
                     }
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-4 LTP",
                     "link type(s)": "OTU4",
                     "physical node": "S7",
                     "unnumberd/ifIndex": 3,
                     "port type": "inter-domain port",
                     "connected to": "S11"
                   },
                   "tp-id": "4",
                   "ietf-te-topology:te-tp-id": 4,
                   "ietf-te-topology:te": {
                     "name": "AN1-4 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU4"
                             }
                           }
                         ]
                       }
                     ],
                     "// __COMMENT__ inter-domain-plug-id": "S7-S11 Plu\
   \g-id (0x000711 -> AAcR)",
                     "inter-domain-plug-id": "AAcR",
                     "// __NOT-PRESENT__ inter-layer-lock-id": "ODU Ser\
   \ver Layer topology not exposed",
                     "admin-status": "up",
                     "oper-status": "up",
                     "// __NOT-PRESENT__ ietf-otn-topology:client-svc":\
   \ "OTN inter-domain link"
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-5 LTP",
                     "link type(s)": "OTU4",
                     "physical node": "S8",
                     "unnumberd/ifIndex": 4,
                     "port type": "inter-domain port",
                     "connected to": "S12"
                   },
                   "tp-id": "5",
                   "ietf-te-topology:te-tp-id": 5,
                   "ietf-te-topology:te": {
                     "name": "AN1-5 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU4"
                             }
                           }
                         ]
                       }
                     ],
                     "// __COMMENT__ inter-domain-plug-id": "S8.S12 Plu\
   \g-id (0x000812 -> AAgS)",
                     "inter-domain-plug-id": "AAgS",
                     "// __NOT-PRESENT__ inter-layer-lock-id": "ODU Ser\
   \ver Layer topology not exposed",
                     "admin-status": "up",
                     "oper-status": "up",
                     "// __NOT-PRESENT__ ietf-otn-topology:client-svc":\
   \ "OTN inter-domain link"
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-6 LTP",
                     "link type(s)": "OTU4",
                     "physical node": "S8",
                     "unnumberd/ifIndex": 5,
                     "port type": "inter-domain port",
                     "connected to": "S32"
                   },
                   "tp-id": "6",
                   "ietf-te-topology:te-tp-id": 6,
                   "ietf-te-topology:te": {
                     "name": "AN1-6 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU4"
                             }
                           }
                         ]
                       }
                     ],
                     "// __COMMENT__ inter-domain-plug-id": "S8.S32 Plu\
   \g-id (0x000832 -> AAgy)",
                     "inter-domain-plug-id": "AAgy",
                     "// __NOT-PRESENT__ inter-layer-lock-id": "ODU Ser\
   \ver Layer topology not exposed",
                     "admin-status": "up",
                     "oper-status": "up",
                     "// __NOT-PRESENT__ ietf-otn-topology:client-svc":\
   \ "OTN inter-domain link"
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-7 LTP",
                     "link type(s)": "OTU4",
                     "physical node": "S2",
                     "unnumberd/ifIndex": 3,
                     "port type": "inter-domain port",
                     "connected to": "S31"
                   },
                   "tp-id": "7",
                   "ietf-te-topology:te-tp-id": 7,
                   "ietf-te-topology:te": {
                     "name": "AN1-7 LTP",
                     "interface-switching-capability": [
                       {
                         "// __COMMENT__ encoding and switching-capabil\
   \ity": "OTN (ODU)",
                         "switching-capability": "ietf-te-types:switchi\
   \ng-otn",
                         "encoding": "ietf-te-types:lsp-encoding-oduk",
                         "max-lsp-bandwidth": [
                           {
                             "priority": 0,
                             "te-bandwidth": {
                               "ietf-otn-topology:odu-type": "ietf-laye\
   \r1-types:ODU4"
                             }
                           }
                         ]
                       }
                     ],
                     "// __COMMENT__ inter-domain-plug-id": "S2-S31 Plu\
   \g-id (0x000231 -> AAIx)",
                     "inter-domain-plug-id": "AAIx",
                     "// __NOT-PRESENT__ inter-layer-lock-id": "ODU Ser\
   \ver Layer topology not exposed",
                     "admin-status": "up",
                     "oper-status": "up",
                     "// __NOT-PRESENT__ ietf-otn-topology:client-svc":\
   \ "OTN inter-domain link"
                   }
                 }
               ]
             }
           ],
           "ietf-network-topology:link": [
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Access Link from AN1-1",
                 "type": "Multi-function access link (OTU2, STM-64 and \
   \10GE)",
                 "physical link": "Link from S3-1 to R1"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/1",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 1
               },
               "// __NOT-PRESENT__ destination": "access link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Access Link from AN1-1",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "interface-switching-capability": [
                     {
                       "// __COMMENT__ encoding and switching-capabilit\
   \y": "OTN (ODU)",
                       "switching-capability": "ietf-te-types:switching\
   \-otn",
                       "encoding": "ietf-te-types:lsp-encoding-oduk",
                       "max-lsp-bandwidth": [
                         {
                           "priority": 0,
                           "te-bandwidth": {
                             "ietf-otn-topology:odu-type": "ietf-layer1\
   \-types:ODU2"
                           }
                         }
                       ]
                     }
                   ],
                   "// __COMMENT__ label-restrictions": "Outside the sc\
   \ope of this JSON example",
                   "max-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 1
                         }
```

```
                    ]
                  }
                },
                "max-resv-link-bandwidth": {
                  "te-bandwidth": {
                    "ietf-otn-topology:odulist": [
                      {
                        "odu-type": "ietf-layer1-types:ODU2",
                        "number": 1
                      }
                    ]
                  }
                },
                "unreserved-bandwidth": [
                  {
                    "priority": 0,
                    "te-bandwidth": {
                      "ietf-otn-topology:odulist": [
                        {
                          "odu-type": "ietf-layer1-types:ODU2",
                          "number": 1
                        }
                      ]
                    }
                  }
                ],
                "// __NOT-PRESENT__ ietf-otn-topology:tsg": "Access \
\Link with no HO-ODU termination and LO-ODU switching",
                "admin-status": "up"
              },
              "oper-status": "up",
              "// __NOT-PRESENT__ is-transitional": "It is not a tra\
\nsitional link"
            }
          },
          {
            "// __DESCRIPTION__:__LINK__": {
              "name": "Access Link from AN1-2",
              "type": "Multi-function access link (OTU2 and STM-64)",
              "physical link": "Link from S6-2 to R3"
            },
            "link-id": "teNodeId/10.0.0.1/teLinkId/2",
            "source": {
              "source-node": "10.0.0.1",
              "source-tp": 2
            },
            "// __NOT-PRESENT__ destination": "access link",
            "ietf-te-topology:te": {
              "te-link-attributes": {
                "name": "Access Link from AN1-2",
                "// __NOT-PRESENT__ external-domain": "The plug-id i\
\s used instead of this container",
                "// __NOT-PRESENT__ is-abstract": "The access link i\
\s not abstract",
                "interface-switching-capability": [
                  {
                    "// __COMMENT__ encoding and switching-capabilit\
\y": "OTN (ODU)",
                    "switching-capability": "ietf-te-types:switching\
\-otn",
                    "encoding": "ietf-te-types:lsp-encoding-oduk",
                    "max-lsp-bandwidth": [
                      {
                        "priority": 0,
                        "te-bandwidth": {
                          "ietf-otn-topology:odu-type": "ietf-layer1\
\-types:ODU2"
                        }
                      }
                    ]
                  }
                ],
                "// __COMMENT__ label-restrictions": "Outside the sc\
\ope of this JSON example",
                "max-link-bandwidth": {
                  "te-bandwidth": {
                    "ietf-otn-topology:odulist": [
                      {
                        "odu-type": "ietf-layer1-types:ODU2",
                        "number": 1
                      }
                    ]
                  }
                },
                "max-resv-link-bandwidth": {
                  "te-bandwidth": {
                    "ietf-otn-topology:odulist": [
                      {
```

```
                        "odu-type": "ietf-layer1-types:ODU2",
                        "number": 1
                      }
                    ]
                  }
                },
                "unreserved-bandwidth": [
                  {
                    "priority": 0,
                    "te-bandwidth": {
                      "ietf-otn-topology:odulist": [
                        {
                          "odu-type": "ietf-layer1-types:ODU2",
                          "number": 1
                        }
                      ]
                    }
                  }
                ],
                "// __NOT-PRESENT__ ietf-otn-topology:tsg": "Access \
\Link with no HO-ODU termination and LO-ODU switching",
                "admin-status": "up"
              },
              "oper-status": "up",
              "// __NOT-PRESENT__ is-transitional": "It is not a tra\
\nsitional link"
            }
          },
          {
            "// __DESCRIPTION__:__LINK__": {
              "name": "Access Link from AN1-3",
              "type": "STM-64 Access link",
              "physical link": "Link from S6-3 to R4"
            },
            "link-id": "teNodeId/10.0.0.1/teLinkId/3",
            "source": {
              "source-node": "10.0.0.1",
              "source-tp": 3
            },
            "// __NOT-PRESENT__ destination": "access link",
            "ietf-te-topology:te": {
              "te-link-attributes": {
                "name": "Access Link from AN1-3",
                "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "// __NOT-PRESENT__ interface-switching-capability":\
   \ "STM-64 Access Link only (no ODU switching)",
                   "// __NOT-PRESENT__ max-link-bandwidth": "STM-64 Acc\
   \ess Link only (no ODU switching)",
                   "// __NOT-PRESENT__ max-resv-link-bandwidth": "STM-6\
   \4 Access Link only (no ODU switching)",
                   "// __NOT-PRESENT__ unreserved-bandwidth": "STM-64 A\
   \ccess Link only (no ODU switching)",
                   "// __NOT-PRESENT__ ietf-otn-topology:tsg": "STM-64 \
   \Access Link only (no HO-ODU termination and LO-ODU switching)",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             },
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Inter-domain Link from AN1-4",
                 "type": "OTU4 inter-domain link",
                 "physical link": "Link from S7-3 to S11"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/4",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 4
               },
               "// __NOT-PRESENT__ destination": "inter-domain link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Inter-domain Link from AN1-4",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "interface-switching-capability": [
                     {
                       "// __COMMENT__ encoding and switching-capabilit\
   \y": "OTN (ODU)",
                       "switching-capability": "ietf-te-types:switching\
   \-otn",
                       "encoding": "ietf-te-types:lsp-encoding-oduk",
                       "max-lsp-bandwidth": [
                         {
                           "priority": 0,
                           "te-bandwidth": {
                             "ietf-otn-topology:odu-type": "ietf-layer1\
   \-types:ODU4"
                           }
                         }
                       ]
                     }
                   ],
                   "// __COMMENT__ label-restrictions": "Outside the sc\
   \ope of this JSON example",
                   "max-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "max-resv-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "unreserved-bandwidth": [
                     {
                       "priority": 0,
                       "te-bandwidth": {
                         "ietf-otn-topology:odulist": [
                           {
                             "odu-type": "ietf-layer1-types:ODU4",
                             "number": 1
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU2",
                             "number": 10
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU0",
                             "number": 80
                           }
                         ]
                       }
                     }
                   ],
                   "ietf-otn-topology:tsg": "ietf-layer1-types:tsg-1.25\
   \G",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             },
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Inter-domain Link from AN1-5",
                 "type": "OTU4 inter-domain link",
                 "physical link": "Link from S8-4 to S12"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/5",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 5
               },
               "// __NOT-PRESENT__ destination": "inter-domain link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Inter-domain Link from AN1-5",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "interface-switching-capability": [
                     {
                       "// __COMMENT__ encoding and switching-capabilit\
   \y": "OTN (ODU)",
                       "switching-capability": "ietf-te-types:switching\
   \-otn",
                       "encoding": "ietf-te-types:lsp-encoding-oduk",
                       "max-lsp-bandwidth": [
                         {
                           "priority": 0,
                           "te-bandwidth": {
                             "ietf-otn-topology:odu-type": "ietf-layer1\
   \-types:ODU4"
                           }
                         }
                       ]
                     }
                   ],
                   "// __COMMENT__ label-restrictions": "Outside the sc\
   \ope of this JSON example",
                   "max-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "max-resv-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "unreserved-bandwidth": [
                     {
                       "priority": 0,
                       "te-bandwidth": {
                         "ietf-otn-topology:odulist": [
                           {
                             "odu-type": "ietf-layer1-types:ODU4",
                             "number": 1
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU2",
                             "number": 10
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU0",
                             "number": 80
                           }
                         ]
                       }
                     }
                   ],
                   "ietf-otn-topology:tsg": "ietf-layer1-types:tsg-1.25\
   \G",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             },
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Inter-domain Link from AN1-6",
                 "type": "OTU4 inter-domain link",
                 "physical link": "Link from S8-5 to S32"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/6",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 6
               },
               "// __NOT-PRESENT__ destination": "inter-domain link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Inter-domain Link from AN1-6",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "interface-switching-capability": [
                     {
                       "// __COMMENT__ encoding and switching-capabilit\
   \y": "OTN (ODU)",
                       "switching-capability": "ietf-te-types:switching\
   \-otn",
                       "encoding": "ietf-te-types:lsp-encoding-oduk",
                       "max-lsp-bandwidth": [
                         {
                           "priority": 0,
                           "te-bandwidth": {
                             "ietf-otn-topology:odu-type": "ietf-layer1\
   \-types:ODU4"
                           }
                         }
                       ]
                     }
                   ],
                   "// __COMMENT__ label-restrictions": "Outside the sc\
   \ope of this JSON example",
                   "max-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "max-resv-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "unreserved-bandwidth": [
                     {
                       "priority": 0,
                       "te-bandwidth": {
                         "ietf-otn-topology:odulist": [
                           {
                             "odu-type": "ietf-layer1-types:ODU4",
                             "number": 1
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU2",
                             "number": 10
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU0",
                             "number": 80
                           }
                         ]
                       }
                     }
                   ],
                   "ietf-otn-topology:tsg": "ietf-layer1-types:tsg-1.25\
   \G",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             },
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Inter-domain Link from AN1-7",
                 "type": "OTU4 inter-domain link",
                 "physical link": "Link from S2-3 to S31"
               },
               "link-id": "teNodeId/10.0.0.1teLinkId/7",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 7
               },
               "// __NOT-PRESENT__ destination": "inter-domain link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Inter-domain Link from AN1-7",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "interface-switching-capability": [
                     {
                       "// __COMMENT__ encoding and switching-capabilit\
   \y": "OTN (ODU)",
                       "switching-capability": "ietf-te-types:switching\
   \-otn",
                       "encoding": "ietf-te-types:lsp-encoding-oduk",
                       "max-lsp-bandwidth": [
                         {
                           "priority": 0,
                           "te-bandwidth": {
                             "ietf-otn-topology:odu-type": "ietf-layer1\
   \-types:ODU4"
                           }
                         }
                       ]
                     }
                   ],
                   "// __COMMENT__ label-restrictions": "Outside the sc\
   \ope of this JSON example",
                   "max-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "max-resv-link-bandwidth": {
                     "te-bandwidth": {
                       "ietf-otn-topology:odulist": [
                         {
                           "odu-type": "ietf-layer1-types:ODU4",
                           "number": 1
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU2",
                           "number": 10
                         },
                         {
                           "odu-type": "ietf-layer1-types:ODU0",
                           "number": 80
                         }
                       ]
                     }
                   },
                   "unreserved-bandwidth": [
                     {
                       "priority": 0,
                       "te-bandwidth": {
                         "ietf-otn-topology:odulist": [
                           {
                             "odu-type": "ietf-layer1-types:ODU4",
                             "number": 1
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU2",
                             "number": 10
                           },
                           {
                             "odu-type": "ietf-layer1-types:ODU0",
                             "number": 80
                           }
                         ]
                       }
                     }
                   ],
                   "ietf-otn-topology:tsg": "ietf-layer1-types:tsg-1.25\
   \G",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             }
```

```
           ]
         }
       ]
     }
   }
```

B.1.2.   JSON Code: mpi1-eth-topology.json

This is the JSON code reporting the ETH Topology @ MPI1:

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

   {
     "// __LAST_UPDATE__": "October 16, 2019",
     "// __TITLE__": "ETH Black Topology @ MPI1",
     "// __REFERENCE_DRAFTS__": {
       "ietf-routing-types@2017-12-04": "rfc8294",
       "ietf-te-types@2019-07-05": "draft-ietf-teas-yang-te-types-10",
       "ietf-network@2018-02-26": "rfc8345",
       "ietf-network-topology@2018-02-26": "rfc8345",
       "ietf-te-topology@2019-02-07": "draft-ietf-teas-yang-te-topo-22",
       "ietf-eth-tran-types@2019-03-27": "draft-ietf-ccamp-client-signa\
   \l-yang-00",
       "ietf-eth-te-topology@2019-07-08": "draft-zheng-ccamp-client-top\
   \o-yang-06"
     },
     "// __MISSING_ATTRIBUTES__": true,
     "ietf-network:networks": {
       "network": [
         {
           "network-id": "providerId/201/clientId/300/topologyId/eth-bl\
   \ack-topology",
           "network-types": {
             "ietf-te-topology:te-topology": {
               "ietf-eth-te-topology:eth-tran-topology": {}
             }
           },
           "ietf-te-topology:te-topology-identifier": {
             "provider-id": 201,
             "client-id": 300,
             "te-topology-id": "eth-black-topology"
           },
           "// __COMMENT__ ietf-te-topology:te": "presence container re\
   \quires: provider-id, client-id and te-topology-id",
           "ietf-te-topology:te": {
             "name": "ETH Black Topology @ MPI1"
           },
           "ietf-network:node": [
             {
               "// __NODE__:__DESCRIPTION__": {
                 "name": "AN1",
                 "identifier": "10.0.0.1",
                 "type": "Abstract Node",
                 "physical node(s)": "The whole network domain 1"
               },
               "node-id": "10.0.0.1",
               "ietf-te-topology:te-node-id": "10.0.0.1",
               "// __COMMENT__ supporting-node": "Not used because topo\
   \logy hierarchy is outside the scope of this JSON example",
               "ietf-te-topology:te": {
                 "te-node-attributes": {
                   "name": "AN11",
                   "is-abstract": {},
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ tunnel-termination-point": "ETH Ac\
   \cess Links only (no ETH TE switching)"
               },
               "ietf-network-topology:termination-point": [
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-1 LTP",
                     "link type(s)": "Multi-function (OTU2, STM-64 and \
   \10GE)",
                     "physical node": "S3",
                     "unnumberd/ifIndex": 1,
                     "port type": "tributary port",
                     "connected to": "R1"
                   },
                   "tp-id": "1",
                   "ietf-te-topology:te-tp-id": 1,
                   "ietf-te-topology:te": {
                     "name": "AN1-1 LTP",
                     "// __NOT-PRESENT__ interface-switching-capability\
   \": "ETH Access Link only (no ETH TE switching)",
                     "// __COMMENT__ inter-domain-plug-id": "Use of plu\
   \g-id for access Link is outside the scope of this document",
                     "// __COMMENT__ inter-layer-lock-id": "AN1-1 ILL-I\
   \D (1)",
                     "inter-layer-lock-id": [
                       1
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   },
                   "// __COMMENT__ ingress-bandwidth-profile": "Outside\
   \ the scope of this JSON example",
                   "ietf-eth-te-topology:eth-svc": {
                     "client-facing": true,
                     "supported-classification": {
                       "port-classification": true,
                       "vlan-classification": {
                         "vlan-tag-classification": true,
                         "outer-tag": {
                           "supported-tag-types": [
                             "ietf-eth-tran-types:classify-c-vlan"
                           ],
                           "vlan-range": "1-4094"
                         }
                       }
                     },
                     "supported-vlan-operations": {
                       "transparent-vlan-operations": true
                     }
                   }
                 },
                 {
                   "// __DESCRIPTION__:__LTP__": {
                     "name": "AN1-8 LTP",
                     "link type(s)": "10GE",
                     "physical node": "S6",
                     "unnumberd/ifIndex": 1,
                     "port type": "tributary port",
                     "connected to": "R2"
                   },
                   "tp-id": "8",
                   "ietf-te-topology:te-tp-id": 8,
                   "ietf-te-topology:te": {
                     "name": "AN1-8 LTP",
                     "// __COMMENT__ inter-layer-lock-id": "AN1-8 ILL-I\
   \D (8)",
                     "// __NOT-PRESENT__ interface-switching-capability\
   \": "ETH Access Link only (no ETH TE switching)",
                     "// __COMMENT__ inter-domain-plug-id": "Use of plu\
   \g-id for access Link is outside the scope of this document",
                     "inter-layer-lock-id": [
                       8
                     ],
                     "admin-status": "up",
                     "oper-status": "up"
                   },
                   "// __COMMENT__ ingress-bandwidth-profile": "Outside\
   \ the scope of this JSON example",
                   "ietf-eth-te-topology:eth-svc": {
                     "client-facing": true,
                     "supported-classification": {
                       "port-classification": true,
                       "vlan-classification": {
                         "vlan-tag-classification": true,
                         "outer-tag": {
                           "supported-tag-types": [
                             "ietf-eth-tran-types:classify-c-vlan"
                           ],
                           "vlan-range": "1-4094"
                         }
                       }
                     },
                     "supported-vlan-operations": {
                       "transparent-vlan-operations": true
                     }
                   }
                 }
               ]
             }
           ],
           "ietf-network-topology:link": [
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Access Link from AN1-1",
                 "type": "Multi-function access link (OTU2, STM-64 and \
   \10GE)",
                 "physical link": "Link from S3-1 to R1"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/1",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 1
               },
               "// __NOT-PRESENT__ destination": "access link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Access Link from AN1-1",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
   \s used instead of this container",
                   "// __NOT-PRESENT__ is-abstract": "The access link i\
   \s not abstract",
                   "// __NOT-PRESENT__ interface-switching-capability":\
   \ "ETH Access Link only (no ETH TE switching)",
                   "// __NOT-PRESENT__ label-restrictions": "ETH Access\
   \ Link only (no ETH TE switching)",
                   "// __NOT-PRESENT__ max-link-bandwidth": "ETH Access\
   \ Link only (no ETH TE switching)",
                   "// __NOT-PRESENT__ max-resv-link-bandwidth": "ETH A\
   \ccess Link only (no ETH TE switching)",
                   "// __NOT-PRESENT__ unreserved-bandwidth": "ETH Acce\
   \ss Link only (no ETH TE switching)",
                   "admin-status": "up"
                 },
                 "oper-status": "up",
                 "// __NOT-PRESENT__ is-transitional": "It is not a tra\
   \nsitional link"
               }
             },
             {
               "// __DESCRIPTION__:__LINK__": {
                 "name": "Access Link from AN1-8",
                 "type": "10GE access link",
                 "physical link": "Link from S6-1 to R2"
               },
               "link-id": "teNodeId/10.0.0.1/teLinkId/8",
               "source": {
                 "source-node": "10.0.0.1",
                 "source-tp": 8
               },
               "// __NOT-PRESENT__ destination": "access link",
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "name": "Access Link from AN1-8",
                   "// __NOT-PRESENT__ external-domain": "The plug-id i\
\s used instead of this container",
                "// __NOT-PRESENT__ is-abstract": "The access link i\
\s not abstract",
                "// __NOT-PRESENT__ interface-switching-capability":\
\ "ETH Access Link only (no ETH TE switching)",
                "// __NOT-PRESENT__ label-restrictions": "ETH Access\
\ Link only (no ETH TE switching)",
                "// __NOT-PRESENT__ max-link-bandwidth": "ETH Access\
\ Link only (no ETH TE switching)",
                "// __NOT-PRESENT__ max-resv-link-bandwidth": "ETH A\
\ccess Link only (no ETH TE switching)",
                "// __NOT-PRESENT__ unreserved-bandwidth": "ETH Acce\
\ss Link only (no ETH TE switching)",
                "admin-status": "up"
              },
              "oper-status": "up",
              "// __NOT-PRESENT__ is-transitional": "It is not a tra\
\nsitional link"
            }
          }
        ]
      }
    ]
  }
}
```

B.2. JSON Examples for Service Configuration

B.2.1. JSON Code: mpi1-odu2-service-config.json

This is the JSON code reporting the ODU2 transit service configuration @ MPI1:

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

{
  "// __LAST_UPDATE__": "October 23, 2019",
  "// __TITLE__": "ODU2 Service Configuration @ MPI1",
  "// __REFERENCE_DRAFTS__": {
    "ietf-routing-types@2017-12-04": "rfc8294",
    "ietf-te-types@2019-07-05": "draft-ietf-teas-yang-te-types-10",
    "ietf-layer1-types@2019-09-09": "draft-ietf-ccamp-layer1-types-0\
\2",
    "ietf-te@2019-04-09": "draft-ietf-teas-yang-te-21",
       "ietf-otn-tunnel@2019-10-23": "draft-ietf-ccamp-otn-tunnel-model\
   \-08"
     },
     "// __MISSING_ATTRIBUTES__": true,
     "// __RESTCONF_OPERATION__": {
       "operation": "POST",
       "url": "http://{{PNC1-ADDR}}/restconf/data/ietf-te:te/tunnels"
     },
     "ietf-te:te": {
       "tunnels": {
         "tunnel": [
           {
             "name": "mpi1-odu2-service",
             "// __COMMENT__ identifier": "ODU2-SERVICE-TUNNEL-ID @ MPI\
   \1",
             "identifier": 1,
             "description": "ODU2 Service implemented by ODU2 OTN Tunne\
   \l Segment @ MPI1",
             "// __COMMENT__ encoding and switching-type": "OTN (ODU)",
             "encoding": "ietf-te-types:lsp-encoding-oduk",
             "switching-type": "ietf-te-types:switching-otn",
             "// __NOT-PRESENT__ source": "Transit tunnel segment",
             "// __NOT-PRESENT__ src-tp-id": "Transit tunnel segment",
             "// __NOT-PRESENT__ destination": "Transit tunnel segment",
             "// __NOT-PRESENT__ dst-tp-id": "Transit tunnel segment",
             "bidirectional": true,
             "// __ DEFAULT __ protection": {
               "// __ DEFAULT __ enable": false
             },
             "// __ DEFAULT __ restoration": {
               "// __ DEFAULT __ enable": false
             },
             "// __COMMENT__ te-topology-identifier": "ODU Black Topolo\
   \gy @ MPI1",
             "te-topology-identifier": {
               "provider-id": 201,
               "client-id": 300,
               "topology-id": "otn-black-topology"
             },
             "te-bandwidth": {
               "ietf-otn-tunnel:odu-type": "ietf-layer1-types:ODU2"
             },
             "provisioning-state": "ietf-te-types:tunnel-state-up",
             "p2p-primary-paths": {
               "p2p-primary-path": [
                 {
                   "name": "mpi1-odu2-service-primary-path",
                   "// __NOT-PRESENT__ te-bandwidth": "The tunnel bandw\
   \idth is used",
                   "explicit-route-objects-always": {
                     "route-object-include-exclude": [
                       {
                         "// __COMMENT__": "Tunnel hand-off OTU2 ingres\
   \s interface (S3-1 -> AN1-1)",
                         "index": 1,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "unnumbered-link-hop": {
                           "// __COMMENT__ node-id": "AN1 NODE-ID",
                           "node-id": "10.0.0.1",
                           "// __COMMENT__ link-tp-id": "AN1-1 LTP",
                           "link-tp-id": 1,
                           "// __DEFAULT__ hop-type": "strict",
                           "// __DEFAULT__ direction": "outgoing"
                         }
                       },
                       {
                         "// __COMMENT__": "Tunnel hand-off ODU2 ingres\
   \s label (ODU2 over OTU2) at S3-1 (AN1-1)",
                         "index": 2,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "label-hop": {
                           "te-label": {
                             "ietf-otn-tunnel:tpn": 1,
                             "// __NOT-PRESENT__ ietf-otn-tunnel:tsg": \
   \"Not applicable for ODUk over OTUk",
                             "// __NOT-PRESENT__ ietf-otn-tunnel:ts-lis\
   \t": "Not applicable for ODUk over OTUk",
                             "// __DEFAULT__ direction": "forward"
                           }
                         }
                       },
                       {
                         "// __COMMENT__": "Tunnel hand-off OTU4 egress\
   \ interface (S2-3 -> AN1-7)",
                         "index": 3,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "unnumbered-link-hop": {
                           "// __COMMENT__ node-id": "AN1 Node",
                           "node-id": "10.0.0.1",
                           "// __COMMENT__ link-tp-id": "AN1-7 LTP",
                           "link-tp-id": 7,
                           "// __DEFAULT__ hop-type": "strict",
                           "// __DEFAULT__ direction": "outgoing"
                         }
                       },
                       {
                         "// __COMMENT__": "Tunnel hand-off ODU2 egress\
   \ label (ODU2 over OTU4) at S2-3 (AN1-7)",
                         "index": 4,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "label-hop": {
                           "te-label": {
                             "ietf-otn-tunnel:tpn": 1,
                             "ietf-otn-tunnel:tsg": "ietf-layer1-types:\
   \tsg-1.25G",
                             "ietf-otn-tunnel:ts-list": "1-8",
                             "// __DEFAULT__ direction": "forward"
                           }
                         }
                       }
                     ]
                   }
                 }
               ]
             }
           }
         ]
       }
     }
   }
```

B.2.2. JSON Code: mpi1-odu2-tunnel-config.json

This is the JSON code reporting the ODU2 head tunnel segment configuration @ MPI1:

```
   ========== NOTE: '\\' line wrapping per BCP XXX (RFC XXXX) ==========
   {
     "// __LAST_UPDATE__": "October 23, 2019",
     "// __TITLE__": "ODU2 Tunnel Configuration @ MPI1",
     "// __REFERENCE_DRAFTS__": {
       "ietf-routing-types@2017-12-04": "rfc8294",
       "ietf-te-types@2019-07-05": "draft-ietf-teas-yang-te-types-10",
       "ietf-layer1-types@2019-09-09": "draft-ietf-ccamp-layer1-types-0\
   \2",
       "ietf-te@2019-04-09": "draft-ietf-teas-yang-te-21",
       "ietf-otn-tunnel@2019-10-23": "draft-ietf-ccamp-otn-tunnel-model\
   \-08"
     },
     "// __MISSING_ATTRIBUTES__": true,
     "// __RESTCONF_OPERATION__": {
       "operation": "POST",
       "url": "http://{{PNC1-ADDR}}/restconf/data/ietf-te:te/tunnels"
     },
     "ietf-te:te": {
       "tunnels": {
         "tunnel": [
           {
             "name": "mpi1-odu2-tunnel",
             "// __COMMENT__ identifier": "ODU2-TUNNEL-ID @ MPI1",
             "identifier": 2,
             "description": "TNBI Example for an ODU2 Head Tunnel Segme\
   \nt @ MPI1",
             "// __COMMENT__ encoding and switching-type": "OTN (ODU)",
             "encoding": "ietf-te-types:lsp-encoding-oduk",
             "switching-type": "ietf-te-types:switching-otn",
             "// __COMMENT__ source": "AN1 Node-ID",
             "source": "10.0.0.1",
             "// __COMMENT__ src-tp-id": "AN1-1 TTP-ID (1 -> 0x01 -> '0\
   \1')",
             "src-tp-id": "01",
             "// __NOT-PRESENT__ destination": "Head tunnel segment",
             "// __NOT-PRESENT__ dst-tp-id": "Head tunnel segment",
             "bidirectional": true,
             "// __ DEFAULT __ protection": {
               "// __ DEFAULT __ enable": false
             },
             "// __ DEFAULT __ restoration": {
               "// __ DEFAULT __ enable": false
             },
             "// __COMMENT__ te-topology-identifier": "ODU Black Topolo\
   \gy @ MPI1",
             "te-topology-identifier": {
               "provider-id": 201,
               "client-id": 300,
               "topology-id": "otn-black-topology"
             },
             "te-bandwidth": {
               "ietf-otn-tunnel:odu-type": "ietf-layer1-types:ODU2"
             },
             "provisioning-state": "ietf-te-types:tunnel-state-down",
             "p2p-primary-paths": {
               "p2p-primary-path": [
                 {
                   "name": "mpi1-odu2-tunnel-primary-path",
                   "// __NOT-PRESENT__ te-bandwidth": "The tunnel bandw\
   \idth is used",
                   "explicit-route-objects-always": {
                     "route-object-include-exclude": [
                       {
                         "// __COMMENT__": "Tunnel hand-off OTU4 egress\
   \ interface (AN1-7 LTP)",
                         "index": 1,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "unnumbered-link-hop": {
                           "// __COMMENT__ node-id": "AN1 NODE-ID",
                           "node-id": "10.0.0.1",
                           "// __COMMENT__ link-tp-id": "AN1-7 LTP-ID",
                           "link-tp-id": 7,
                           "// __DEFAULT__ hop-type": "strict",
                           "// __DEFAULT__ direction": "outgoing"
                         }
                       },
                       {
                         "// __COMMENT__": "Tunnel hand-off ODU2 egress\
   \ label (ODU2 over OTU4)",
                         "index": 2,
                         "explicit-route-usage": "ietf-te-types:route-i\
   \nclude-object",
                         "label-hop": {
                           "te-label": {
                             "ietf-otn-tunnel:tpn": 2,
                             "ietf-otn-tunnel:tsg": "ietf-layer1-types:\
   \tsg-1.25G",
                             "ietf-otn-tunnel:ts-list": "9-16",
                             "// __DEFAULT__ direction": "forward"
                           }
                         }
                       }
                     ]
                   }
                 }
               ]
             }
           }
         ]
       }
     }
   }
```

B.2.3.   JSON Code: mpi1-epl-service-config.json

This is the JSON code reporting the EPL service configuration @ MPI:

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

   {
     "// __LAST_UPDATE__": "October 16, 2019",
     "// __TITLE__": "EPL Configuration @ MPI1",
     "// __REFERENCE_DRAFTS__": {
       "ietf-routing-types@2017-12-04": "rfc8294",
       "ietf-te-types@2019-07-05": "draft-ietf-teas-yang-te-types-10",
       "ietf-eth-tran-types@2019-03-27": "draft-ietf-ccamp-client-signa\
   \l-yang-00",
       "ietf-eth-tran-service@2019-03-27": "draft-ietf-ccamp-client-sig\
   \nal-yang-00"
     },
     "// __MISSING_ATTRIBUTES__": true,
     "// __RESTCONF_OPERATION__": {
       "operation": "POST",
       "url": "http://{{PNC1-ADDR}}/restconf/data/ietf-eth-tran-service\
   \:etht-svc/etht-svc-instances"
     },
     "ietf-eth-tran-service:etht-svc": {
       "etht-svc-instances": [
         {
           "etht-svc-name": "mpi1-epl-service",
           "etht-svc-descr": "TNBI Example for an EPL over ODU2 Service\
   \ @ MPI1",
           "// __DEFAULT__ etht-svc-type": "ietf-eth-tran-types:p2p-svc\
   \",
           "// __COMMENT__ te-topology-identifier": "ETH Black Topology\
   \ @ MPI1",
           "te-topology-identifier": {
             "provider-id": 201,
             "client-id": 300,
             "topology-id": "eth-black-topology"
           },
           "etht-svc-end-points": [
             {
               "// __COMMENT__": "10GE Service End-Point at the access \
   \interface (S3-1 -> AN1-1)",
               "etht-svc-end-point-name": "mpi1-epl-an1-1-service-end-p\
   \oint",
               "etht-svc-end-point-descr": "Ethernet Service End-Point \
   \at S3-1 (AN1-1) access link",
               "etht-svc-access-points": [
                 {
                   "// __COMMENT__": "10GE Service Access Point at the \
   \access interface (S3-1 -> AN1-1)",
                   "etht-svc-end-point-name": "mpi-epl-an1-1-service-ac\
   \cess-point",
                   "// __COMMENT__ access-node-id": "AN1 NODE-ID",
                   "access-node-id": "10.0.0.1",
                   "// __COMMENT__ access-ltp-id": "AN1-1 LTP-ID",
                   "access-ltp-id": 1
                 }
               ]
             }
           ],
           "service-classification-type": "ietf-eth-tran-types:port-cla\
   \ssification",
           "// __COMMENT__ ingress-egress-bandwidth-profile": "Outside \
   \the scope of this JSON example",
           "// __NOT-PRESENT__ vlan-operations": "Transparent VLAN oper\
   \ations",
           "etht-svc-tunnels": [
             {
               "// __COMMENT__ tunnel-name": "ODU2 Head Tunnel Segment \
   \@ MPI1",
               "tunnel-name": "mpi1-odu2-tunnel"
             }
           ],
           "admin-status": "ietf-te-types:tunnel-admin-state-up"
         }
       ]
     }
   }
```

Authors' Addresses

Italo Busi (Editor)
Huawei

Email: italo.busi@huawei.com

Daniel King (Editor)
Old Dog Consulting

Email: daniel@olddog.co.uk

Haomian Zheng (Editor)
Huawei

Email: zhenghaomian@huawei.com

Yunbin Xu (Editor)
CAICT

Email: xuyunbin@ritt.cn

Yang Zhao
China Mobile

Email: zhaoyangyjy@chinamobile.com

Sergio Belotti
Nokia

Email: sergio.belotti@nokia.com

Gianmarco Bruno
Ericsson

Email: gianmarco.bruno@ericsson.com

Young Lee
Huawei

Email: leeyoung@huawei.com

Victor Lopez
Telefonica

Email: victor.lopezalvarez@telefonica.com

Carlo Perocchio
Ericsson

Email: carlo.perocchio@ericsson.com

Ricard Vilalta
CTTC

Email: ricard.vilalta@cttc.es

Michael Scharf
Hochschule Esslingen - University of Applied Sciences

Email: michael.scharf@hs-esslingen.de

Dieter Beller
Nokia

Email: dieter.beller@nokia.com