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Fabio Peruzzini  
TIM  
Jean-Francois Bouquier  
Vodafone  
Italo Busi  
Huawei  
Daniel King  
Old Dog Consulting  
Daniele Ceccarelli  
Ericsson

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**Applicability of Abstraction and Control of Traffic Engineered  
Networks (ACTN) to Packet Optical Integration (POI)**

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**Abstract**

This document considers the applicability of Abstraction and Control of TE Networks (ACTN) architecture to Packet Optical Integration (POI) in the context of IP/MPLS and optical internetworking. It identifies the YANG data models being defined by the IETF to support this deployment architecture and specific scenarios relevant for Service Providers.

Existing IETF protocols and data models are identified for each multi-layer (packet over optical) scenario with a specific focus on the MPI (Multi-Domain Service Coordinator to Provisioning Network Controllers Interface) in the ACTN architecture.

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## **1. Introduction**

The complete automation of the management and control of Service Providers transport networks (IP/MPLS, optical, and microwave transport networks) is vital for meeting emerging demand for high-bandwidth use cases, including 5G and fiber connectivity services. The Abstraction and Control of TE Networks (ACTN) architecture and interfaces facilitate the automation and operation of complex optical and IP/MPLS networks through standard interfaces and data models. This allows a wide range of network services that can be requested by the upper layers fulfilling almost any kind of service level requirements from a network perspective (e.g. physical diversity, latency, bandwidth, topology, etc.)

Packet Optical Integration (POI) is an advanced use case of traffic engineering. In wide-area networks, a packet network based on the Internet Protocol (IP), and often Multiprotocol Label Switching (MPLS) or Segment Routing (SR), is typically realized on top of an



optical transport network that uses Dense Wavelength Division Multiplexing (DWDM)(and optionally an Optical Transport Network (OTN)layer).

In many existing network deployments, the packet and the optical networks are engineered and operated independently. As a result, there are technical differences between the technologies (e.g., routers compared to optical switches) and the corresponding network engineering and planning methods (e.g., inter-domain peering optimization in IP, versus dealing with physical impairments in DWDM, or very different time scales). In addition, customers needs can be different between a packet and an optical network, and it is not uncommon to use different vendors in both domains. The operation of these complex packet and optical networks is often siloed, as these technology domains require specific skills sets.

The packet/optical network deployment and operation separation are inefficient for many reasons. Both capital expenditure (CAPEX) and operational expenditure (OPEX) could be significantly reduced by integrating the packet and the optical networks. Multi-layer online topology insight can speed up troubleshooting (e.g., alarm correlation) and network operation (e.g., coordination of maintenance events), multi-layer offline topology inventory can improve service quality (e.g., detection of diversity constraint violations) and multi-layer traffic engineering can use the available network capacity more efficiently (e.g., coordination of restoration). In addition, provisioning workflows can be simplified or automated as needed across layers (e.g., to achieve bandwidth-on-demand or to perform activities during maintenance windows).

ACTN framework enables this complete multi-layer and multi-vendor integration of packet and optical networks through Multi-Domain Service Coordinator (MDSC) and packet and optical Provisioning Network Controllers (PNCs).

In this document, critical scenarios for POI are described from the packet service layer perspective and identified the required coordination between packet and optical layers to improve POI deployment and operation. Precise definitions of scenarios can help with achieving a common understanding across different disciplines. The focus of the scenarios are multi-domain packet networks operated as a client of optical networks.

This document analyses the case where the packet networks support multi-domain SR-TE paths and the optical networks could be either a DWDM network or an OTN network (without DWDM layer) or multi-layer



OTN/DWDM network. DWDM networks could be either fixed-grid or flexible-grid.

Multi-layer and multi-domain scenarios, based on reference network described in [section 2](#), and very relevant for Service Providers, are described in [section 4](#) and in section 5.

For each scenario, existing IETF protocols and data models, identified in [section 3.1](#) and [section 3.2](#), are analysed with particular focus on the MPI in the ACTN architecture.

For each multi-layer scenario, the document analyzes how to use the interfaces and data models of the ACTN architecture.

A summary of the gaps identified in this analysis is provided in [section 6](#).

Understanding the level of standardization and the possible gaps will help assess the feasibility of integration between packet and optical DWDM domains (and optionally OTN layer) in an end-to-end multi-vendor service provisioning perspective.

### **[1.1](#). Terminology**

This document uses the ACTN terminology defined in [[RFC8453](#)]

In addition this document uses the following terminology.

Customer service:

the end-to-end service from CE to CE

Network service:

the PE to PE configuration including both the network service layer (VRFs, RT import/export policies configuration) and the network transport layer (e.g. RSVP-TE LSPs). This includes the configuration (on the PE side) of the interface towards the CE (e.g. VLAN, IP address, routing protocol etc.)

Port:

the physical entity that transmits and receives physical signals

**Interface:**

a physical or logical entity that transmits and receives traffic

**Link:**

an association between two interfaces that can exchange traffic directly

**Ethernet link:**

a link between two Ethernet interfaces

**IP link:**

a link between two IP interfaces

**Cross-layer link:**

an Ethernet link between an Ethernet interface on a router and an Ethernet interface on an optical NE

**Intra-domain single-layer Ethernet link:**

an Ethernet link between two Ethernet interfaces on physically adjacent routers that belong to the same P-PNC domain

**Intra-domain single-layer IP link:**

an IP link supported by an intra-domain single-layer Ethernet link

**Inter-domain single-layer Ethernet link:**

an Ethernet link between two Ethernet interfaces on physically adjacent routers which belong to different P-PNC domains

**Inter-domain single-layer IP link:**

an IP link supported by an inter-domain single-layer Ethernet link.

**Intra-domain multi-layer Ethernet link:**

an Ethernet link supported by two cross-layer links and an optical tunnel in between





optical domain. The packet domains controlled by the P-PNCs can be Autonomous Systems (ASes), defined in [[RFC1930](#)], or IGP areas, within the same operator network.

The routers between the packet domains can be either AS Boundary Routers (ASBR) or Area Border Router (ABR): in this document, the generic term Border Router (BR) is used to represent either an ASBR or an ABR.

The MDSC is responsible for coordinating the whole multi-domain multi-layer (packet and optical) network. A specific standard interface (MPI) permits MDSC to interact with the different Provisioning Network Controller (O/P-PNCs).

The MPI interface presents an abstracted topology to MDSC hiding technology-specific aspects of the network and hiding topology details depending on the policy chosen regarding the level of abstraction supported. The level of abstraction can be obtained based on P-PNC and O-PNC configuration parameters (e.g., provide the potential connectivity between any PE and any BR in an SR-TE network).

In the reference network of Figure 1, it is assumed that:

- o The domain boundaries between the packet and optical domains are congruent. In other words, one optical domain supports connectivity between routers in one and only one packet domain;
- o There are no inter-domain physical links between optical domains. Inter-domain physical links exist only:
  - o between packet domains (i.e., between BRs belonging to different packet domains): these links are called inter-domain Ethernet or IP links within this document;
  - o between packet and optical domains (i.e., between routers and optical NEs): these links are called cross-layer links within this document;
  - o between customer sites and the packet network (i.e., between CE devices and PE routers): these links are called access links within this document.
- o All the physical interfaces at inter-domain links are Ethernet physical interfaces.



Although the new optical technologies (e.g., QSFP-DD ZR 400G) allows providing DWDM pluggable interfaces on the routers, the deployment of those pluggable optics is not yet widely adopted by the operators. The reason is that most operators are not yet ready to manage packet and optical networks in a single unified domain. The analysis of the unified use case is outside the scope of this draft.

This document analyses scenarios where all the multi-layer IP links, supported by the optical network, are intra-domain (intra-AS/intra-area), such as PE-BR, PE-P, BR-P, P-P IP links. Therefore the inter-domain IP links are always single-layer links supported by Ethernet physical links.

The analysis of scenarios with multi-layer inter-domain IP links is outside the scope of this document.

Therefore, if inter-domain links between the optical domains exist, they would be used to support multi-domain optical services, which are outside the scope of this document.

The optical network elements (NEs) within the optical domains can be ROADMs or OTN switches, with or without an integrated ROADM function.

### **2.1. Multi-domain Service Coordinator (MDSC) functions**

The MDSC in Figure 1 is responsible for multi-domain and multi-layer coordination across multiple packet and optical domains, as well as to provide multi-layer/multi-domain L2/L3 VPN network services requested by an OSS/Orchestration layer.

From an implementation perspective, the functions associated with MDSC and described in [[RFC8453](#)] may be grouped in different ways.

1. Both the service- and network-related functions are collapsed into a single, monolithic implementation, dealing with the end customer service requests received from the CMI (Customer MDSC Interface) and adapting the relevant network models. An example is represented in Figure 2 of [[RFC8453](#)].
2. An implementation can choose to split the service-related and the network-related functions into different functional entities, as described in [[RFC8309](#)] and in [section 4.2 of \[\[RFC8453\]\(#\)\]](#). In this case, MDSC is decomposed into a top-level Service Orchestrator, interfacing the customer via the CMI, and into a Network Orchestrator interfacing at the southbound with the PNCs. The interface between the Service Orchestrator and the Network Orchestrator is not specified in [[RFC8453](#)].



3. Another implementation can choose to split the MDSC functions between an "higher-level MDSC" (MDSC-H) responsible for packet and optical multi-layer coordination, interfacing with one Optical "lower-level MDSC" (MDSC-L), providing multi-domain coordination between the O-PNCs and one Packet MDSC-L, providing multi-domain coordination between the P-PNCs (see for example Figure 9 of [\[RFC8453\]](#)).
4. Another implementation can also choose to combine the MDSC and the P-PNC functions together.

In the current service provider's network deployments, at the North Bound of the MDSC, instead of a CNC, typically there is an OSS/Orchestration layer. In this case, the MDSC would implement only the Network Orchestration functions, as in [\[RFC8309\]](#) and described in point 2 above. Therefore, the MDSC is dealing with the network services requests received from the OSS/Orchestration layer.

The functionality of the OSS/Orchestration layer and the interface toward the MDSC are usually operator-specific and outside the scope of this draft. Therefore, this document assumes that the OSS/Orchestrator requests the MDSC to set up L2/L3 VPN network services through mechanisms that are outside the scope of this document.

There are two prominent workflow cases when the MDSC multi-layer coordination is initiated:

- o Initiated by a request from the OSS/Orchestration layer to setup L2/L3 VPN network services that requires multi-layer/multi-domain coordination;
- o Initiated by the MDSC itself to perform multi-layer/multi-domain optimizations and/or maintenance activities (e.g. rerouting LSPs with their associated services when putting a resource, like a fibre, in maintenance mode during a maintenance window). Unlike service fulfillment, these workflows are not related to a network service provisioning request being received from the OSS/Orchestration layer.

The latter workflow cases are outside the scope of this document.

This document analyses the use cases where multi-layer coordination is triggered by a network service request received from the OSS/Orchestration layer.



#### **2.1.1.1. Multi-domain L2/L3 VPN network services**

Figure 2 provides an example of an hub & spoke multi-domain L2/L3 VPN with three PEs where the hub PE (PE13) and one spoke PE (PE14) are within the same packet domain and the other spoke PE (PE23) is within a different packet domain.

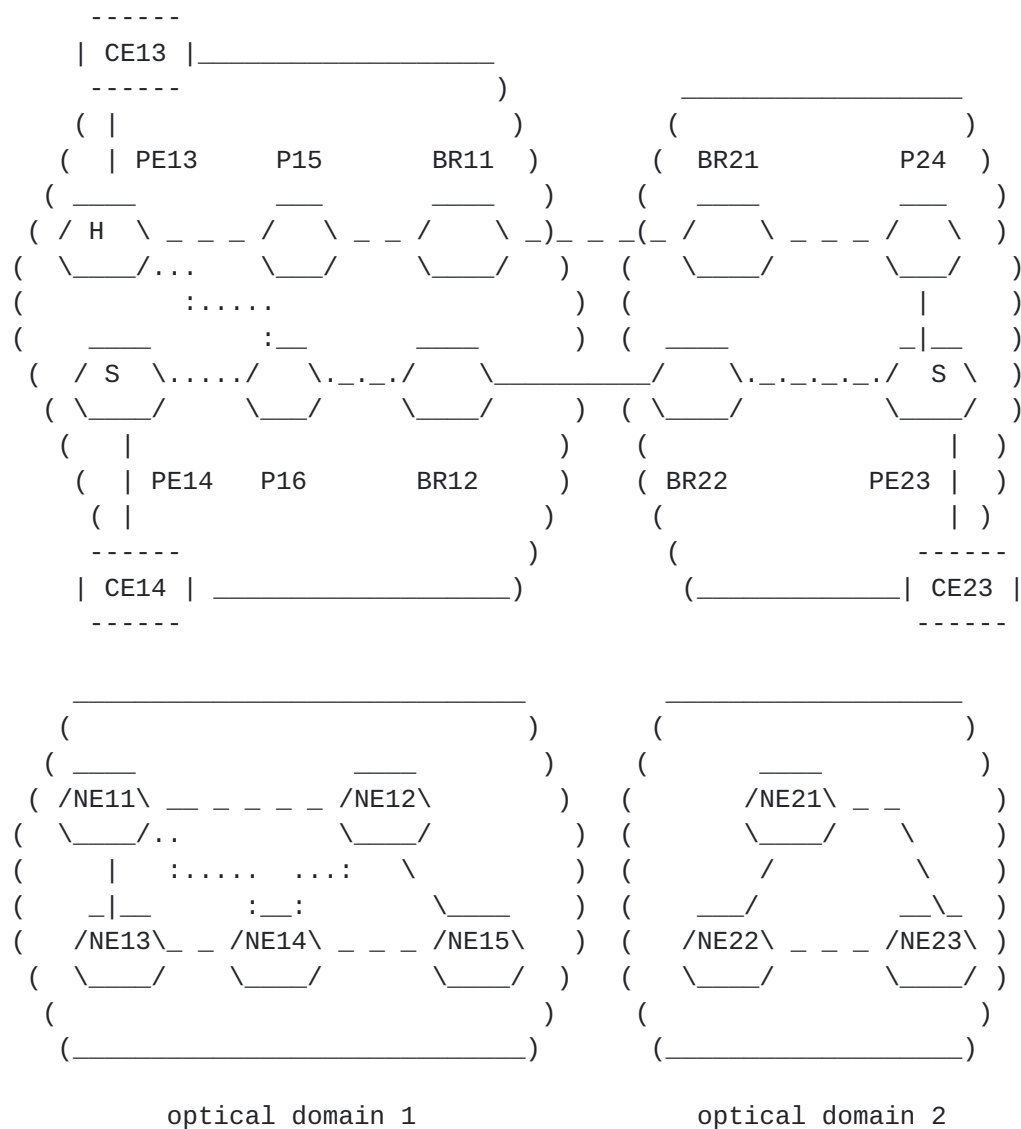


Figure 2 - Multi-domain L3VPN example

There are many options to implement multi-domain L2/L3 VPNs, including:

1. BGP-LU (seamless MPLS)
2. Inter-domain RSVP-TE



### 3. Inter-domain SR-TE

This document provides an analysis of the inter-domain SR-TE option. The analysis of other options is outside the scope of this draft.

It is also assumed that:

- o each packet domain in Figure 2 is implementing SR-TE and the stitching between two domains is done using end-to-end/multi-domain SR-TE;
- o the bandwidth of each intra-domain SR-TE path is managed by its respective P-PNC;
- o binding SID is used for the end-to-end SR-TE path stitching;
- o each packet domain in Figure 2 is using TI-LFA, with SRLG awareness, for local protection within each domain.

In this scenario, one of the key MDSC functions is to identify the multi-domain/multi-layer SR-TE paths to be used to carry the L2/L3 VPN traffic between PEs belonging to different packet domains and to relay this information to the P-PNCs, to ensure that the PEs' forwarding tables (e.g., VRF) are properly configured to steer the L2/L3 VPN traffic over the intended multi-domain/multi-layer SR-TE paths.

The selection of the SR-TE path should take into account the TE requirements and the binding requirements for the L2/L3 VPN network service.

In general the binding requirements for a network service (e.g L2/L3 VPN), can be summarized within three cases:

1. The customer is asking for VPN isolation dynamically creating and binding tunnels to the service such that they are not shared by others services (e.g. VPN).

The level of isolation can be different:

- a) Hard isolation with deterministic latency that means L2/L3 VPN requiring a set of dedicated TE Tunnels (neither sharing with other services nor competing for bandwidth with other tunnels) providing deterministic latency performances
- b) Hard isolation but without deterministic characteristics



- c) Soft isolation that means the tunnels associated with L2/L3 VPN are dedicated to that but can compete for bandwidth with other tunnels.
- 2. The customer does not ask isolation, and could request a VPN service where associated tunnels can be shared across multiple VPNs.

For each SR-TE path required to support the L2/L3 VPN network service, it is possible that:

1. A SR-TE path that meets the TE and binding requirements already exist in the network.
2. An existing SR-TE path could be modified (e.g., through bandwidth increase) to meet the TE and binding requirements:
  - a. The SR-TE path characteristics can be modified only in the packet layer.
  - b. One or more new underlay optical tunnels need to be setup to support the requested changes of the overlay SR-TE paths (multi-layer coordination is required).
3. A new SR-TE path needs to be setup to meet the TE and binding requirements:
  - a. The new SR-TE path reuses existing underlay optical tunnels;
  - b. One or more new underlay optical tunnels need to be setup to support the setup of the new SR-TE path (multi-layer coordination is required).

#### **2.1.2. Multi-domain and multi-layer path computation**

When a new SR-TE path needs to be setup, the MDSC is also responsible to coordinate the multi-layer/multi-domain path computation.

Depending on the knowledge that MDSC has of the topology and configuration of the underlying network domains, three approaches for performing multi-layer/multi-domain path computation are possible:

1. Full Summarization: In this approach, the MDSC has an abstracted TE topology view of all of its, packet and optical, underlying domains.

In this case, the MDSC does not have enough TE topology information to perform multi-layer/multi-domain path computation. Therefore the MDSC delegates the P-PNCs and O-PNCs to perform local path computation within their respective controlled domains and it uses the information returned by the P-PNCs and O-PNCs to compute the optimal multi-domain/multi-layer path.

This approach presents an issue to P-PNC, which does not have the capability of performing a single-domain/multi-layer path computation, since it can not retrieve the topology information from the O-PNCs nor delegate the O-PNC to perform optical path computation.

A possible solution could be to include a CNC function within the P-PNC to request the MDSC multi-domain optical path computation, as shown in Figure 10 of [[RFC8453](#)].

Another solution could be to rely on the MDSC recursive hierarchy, as defined in [section 4.1 of \[RFC8453\]](#), where, for each IP and optical domain pair, a "lower-level MDSC" (MDSC-L) provides the essential multi-layer correlation and the "higher-level MDSC" (MDSC-H) provides the multi-domain coordination.

In this case, the MDSC-H can get an abstract view of the underlying multi-layer domain topologies from its underlying MDSC-L. Each MDSC-L gets the full view of the IP domain topology from P-PNC and can get an abstracted view of the optical domain topology from its underlying O-PNC. In other words, topology abstraction is possible at the MPIs between MDSC-L and O-PNC and between MDSC-L and MDSC-H.

2. Partial summarization: In this approach, the MDSC has full visibility of the TE topology of the packet network domains and an abstracted view of the TE topology of the optical network domains.

The MDSC then has only the capability of performing multi-domain/single-layer path computation for the packet layer (the path can be computed optimally for the two packet domains).

Therefore, the MDSC still needs to delegate the O-PNCs to perform local path computation within their respective domains and it uses the information received by the O-PNCs, together with its TE topology view of the multi-domain packet layer, to perform multi-layer/multi-domain path computation.

3. Full knowledge: In this approach, the MDSC has the complete and enough detailed view of the TE topology of all the network domains (both optical and packet).

In such case MDSC has all the information needed to perform multi-domain/multi-layer path computation, without relying on PNCs.

This approach may present, as a potential drawback, scalability issues and, as discussed in section 2.2. of [[PATH-COMPUTE](#)], performing path computation for optical networks in the MDSC is quite challenging because the optimal paths depend also on vendor-specific optical attributes (which may be different in the two domains if they are provided by different vendors).

This document analyses scenarios where the MDSC uses the partial summarization approach to coordinate multi-domain/multi-layer path computation.

Typically, the O-PNCs are responsible for the optical path computation of services across their respective single domains. Therefore, when setting up the network service, they must consider the connection requirements such as bandwidth, amplification, wavelength continuity, and non-linear impairments that may affect the network service path.

The methods and types of path requirements and impairments, such as those detailed in [[OIA-TOPO](#)], used by the O-PNC for optical path computation are not exposed at the MPI and therefore out of scope for this document.



## **2.2. IP/MPLS Domain Controller and NE Functions**

As highlighted in [section 2.1.1](#), SR-TE is used in the packet domain. Each domain, corresponding to either an IGP area or an Autonomous System (AS) within the same operator network, is controlled by a packet domain controller (P-PNC).

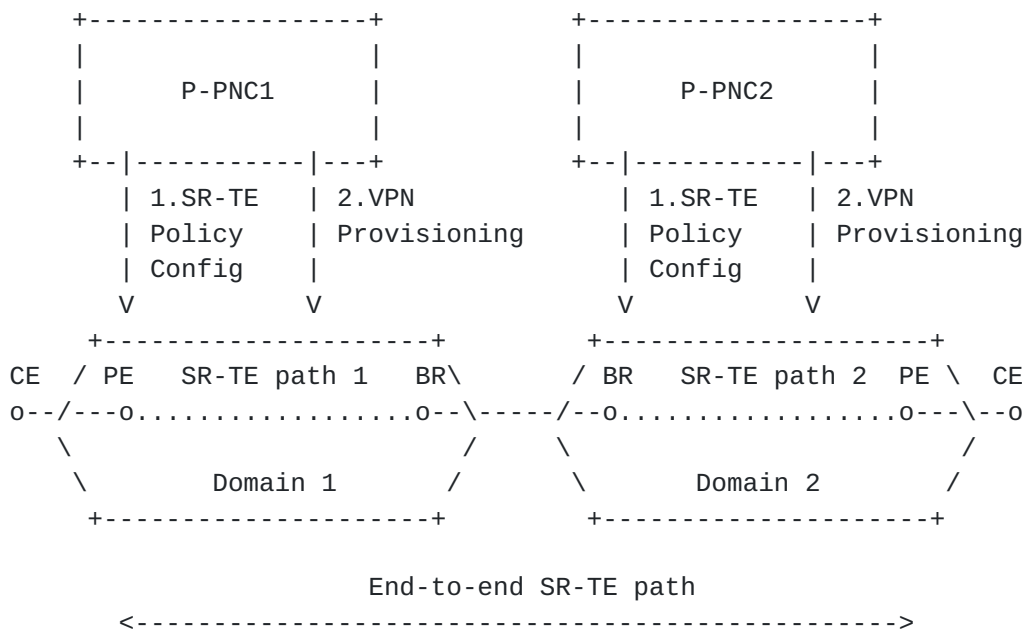
P-PNCs are responsible to setup the SR-TE paths between any two PEs or BRs in their respective controlled domains, as requested by MDSC, and to provide topology information to the MDSC.

With reference to Figure 2, a bidirectional SR-TE path from PE13 in domain 1 to PE23 in domain 2 requires the MDSC to coordinate the actions of:

- o P-PNC1 to push a SID list to PE13 including the Binding SID associated to the SR-TE path in Domain 2 with PE23 as the target destination (forward direction);
- o P-PNC2 to push a SID list to PE23 with including the Binding SID associated to the SR-TE path in Domain 1 with PE13 as the target destination (reverse direction).

With reference to Figure 3, P-PNCs are then responsible:

1. To expose to MDSC their respective detailed TE topology
2. To perform single-layer single-domain local SR-TE path computation, when requested by MDSC between two PEs (for single-domain end-to-end SR-TE path) or between PEs and BRs for an inter-domain SR-TE path selected by MDSC;
3. To configure the ingress PE or BR router in their respective domain with the SID list associated with an SR-TE path;
4. To configure finally the VRF and PE-CE interfaces (Service access points) of the intra-domain and inter-domain network services requested by the MDSC.



### Figure 3 Domain Controller & NE Functions

When requesting the setup of a new SR-TE path, the MDSC provides the P-PNCs with the explicit path to be created or modified. In other words, the MDSC can communicate to the P-PNCs the full list of nodes involved in the path (strict mode). In this case, the P-PNC is just responsible to push to headend PE or BR the list of SIDs to create that explicit SR-TE path.

For scalability purposes, in large packet domains, where multiple engineered paths are available between any two nodes, the MDSC can request a loose path, together with per-domain TE constraints, to allow the P-PNC selecting the intra-domain SR-TE path meeting these constraints.

In such a case it is mandatory that P-PNC signals back to the MDSC which path it has chosen so that the MDSC keeps track of the relevant resources utilization.

An example of that comes from Figure 2. The SR-TE path requested by the MDSC touches PE13 - P16 - BR12 - BR21 - PE23. P-PNC2 knows of two possible paths with the same topology metric, e.g. BR21 - P24 - PE23 and BR21 - BR22 - PE23, but with different load. It may prefer then to steer the traffic on the latter because it is less loaded.



This exception is mentioned here for the sake of completeness but since the network considered in this document does not fall in this scenario, in the rest of the paper the assumption is that the MDSC always provides the explicit list of SID(s) to the P-PNCs to setup or modify the SR-TE path.

### **2.3. Optical Domain Controller and NE Functions**

The optical network provides the underlay connectivity services to IP/MPLS networks. The packet and optical multi-layer coordination is done by the MDSC, as shown in Figure 1.

The O-PNC is responsible to:

- o provide to the MDSC an abstract TE topology view of its underlying optical network resources;
- o perform single-domain local path computation, when requested by the MDSC;
- o perform optical tunnel setup, when requested by the MDSC.

The mechanisms used by O-PNC to perform intra-domain topology discovery and path setup are usually vendor-specific and outside the scope of this document.

Depending on the type of optical network, TE topology abstraction, path computation and path setup can be single-layer (either OTN or WDM) or multi-layer OTN/WDM. In the latter case, the multi-layer coordination between the OTN and WDM layers is performed by the O-PNC.

## **3. Interface protocols and YANG data models for the MPIs**

This section describes general assumptions applicable at all the MPI interfaces, between each PNC (Optical or Packet) and the MDSC, to support the scenarios discussed in this document.

### **3.1. RESTCONF protocol at the MPIs**

The RESTCONF protocol, as defined in [RFC8040], using the JSON representation defined in [RFC7951], is assumed to be used at these interfaces. In addition, extensions to RESTCONF, as defined in [RFC8527], to be compliant with Network Management Datastore Architecture (NMDA) defined in [RFC8342], are assumed to be used as well at these MPI interfaces and also at MDSC NBI interfaces.



### **3.2. YANG data models at the MPIs**

The data models used on these interfaces are assumed to use the YANG 1.1 Data Modeling Language, as defined in [[RFC7950](#)].

#### **3.2.1. Common YANG data models at the MPIs**

As required in [[RFC8040](#)], the "ietf-yang-library" YANG module defined in [[RFC8525](#)] is used to allow the MDSC to discover the set of YANG modules supported by each PNC at its MPI.

Both Optical and Packet PNCs use the following common topology YANG data models at the MPI:

- o The Base Network Model, defined in the "ietf-network" YANG module of [[RFC8345](#)];
- o The Base Network Topology Model, defined in the "ietf-network-topology" YANG module of [[RFC8345](#)], which augments the Base Network Model;
- o The TE Topology Model, defined in the "ietf-te-topology" YANG module of [[RFC8795](#)], which augments the Base Network Topology Model.

Both Optical and Packet PNCs use the common TE Tunnel Model, defined in the "ietf-te" YANG module of [[TE-TUNNEL](#)], at the MPI.

All the common YANG data models are generic and augmented by technology-specific YANG modules, as described in the following sections.

Both Optical and Packet PNCs also use the Ethernet Topology Model, defined in the "ietf-eth-te-topology" YANG module of [[CLIENT-TOPO](#)], which augments the TE Topology Model with Ethernet technology-specific information.

Both Optical and Packet PNCs use the following common notifications YANG data models at the MPI:

- o Dynamic Subscription to YANG Events and Datastores over RESTCONF as defined in [[RFC8650](#)];
- o Subscription to YANG Notifications for Datastores updates as defined in [[RFC8641](#)].



PNCs and MDSCs are compliant with subscription requirements as stated in [[RFC7923](#)].

### **3.2.2. YANG models at the Optical MPIs**

The Optical PNC uses at least one of the following technology-specific topology YANG data models, which augment the generic TE Topology Model:

- o The WSON Topology Model, defined in the "ietf-wson-topology" YANG module of [[RFC9094](#)];
- o the Flexi-grid Topology Model, defined in the "ietf-flexi-grid-topology" YANG module of [[Flexi-TOP0](#)];
- o the OTN Topology Model, as defined in the "ietf-otn-topology" YANG module of [[OTN-TOP0](#)].

The optical PNC uses at least one of the following technology-specific tunnel YANG data models, which augments the generic TE Tunnel Model:

- o The WSON Tunnel Model, defined in the "ietf-wson-tunnel" YANG modules of [[WSON-TUNNEL](#)];
- o the Flexi-grid Tunnel Model, defined in the "ietf-flexi-grid-tunnel" YANG module of [[Flexi-TUNNEL](#)];
- o the OTN Tunnel Model, defined in the "ietf-otn-tunnel" YANG module of [[OTN-TUNNEL](#)].

The optical PNC can optionally use the generic Path Computation YANG RPC, defined in the "ietf-te-path-computation" YANG module of [[PATH-COMPUTE](#)].

Note that technology-specific augmentations of the generic path computation RPC for WSON, Flexi-grid and OTN path computation RPCs have been identified as a gap.

The optical PNC uses the Ethernet Client Signal Model, defined in the "ietf-eth-tran-service" YANG module of [[CLIENT-SIGNAL](#)].

### **3.2.3. YANG data models at the Packet MPIs**

The Packet PNC also uses at least the following technology-specific topology YANG data models:



- o The L3 Topology Model, defined in the "ietf-l3-unicast-topology" YANG module of [[RFC8346](#)], which augments the Base Network Topology Model;
- o the L3 specific data model including extended TE attributes (e.g. performance derived metrics like latency), defined in "ietf-l3-te-topology" and in "ietf-te-topology-packet" YANG modules of [L3-TE-TOPO];
- o the SR Topology Model, defined in the "ietf-sr-mpls-topology" YANG module of [[SR-TE-TOPO](#)].

Need to check the need/applicability of the "ietf-l3-te-topology" in this scenario since it is not described in [[SR-TE-TOPO](#)].

The packet PNC uses at least the following YANG data models:

- o L3VPN Network Model (L3NM), defined in the "ietf-l3vpn-ntw" YANG module of [[RFC9182](#)];
- o L3NM TE Service Mapping, defined in the "ietf-l3nm-te-service-mapping" YANG module of [[TSM](#)];
- o L2VPN Network Model (L2NM), defined in the "ietf-l2vpn-ntw" YANG module of [[L2NM](#)];
- o L2NM TE Service Mapping, defined in the "ietf-l2nm-te-service-mapping" YANG module of [[TSM](#)].

### **[3.3. PCEP](#)**

[RFC8637] examines the applicability of a Path Computation Element (PCE) [[RFC5440](#)] and PCE Communication Protocol (PCEP) to the ACTN framework. It further describes how the PCE architecture applies to ACTN and lists the PCEP extensions that are needed to use PCEP as an ACTN interface. The stateful PCE [[RFC8231](#)], PCE-Initiation [[RFC8281](#)], stateful Hierarchical PCE (H-PCE) [[RFC8751](#)], and PCE as a central controller (PCECC) [[RFC8283](#)] are some of the key extensions that enable the use of PCE/PCEP for ACTN.

Since the PCEP supports path computation in the packet and optical networks, PCEP is well suited for inter-layer path computation. [[RFC5623](#)] describes a framework for applying the PCE-based architecture to interlayer (G)MPLS traffic engineering. Furthermore, the [section 6.1 of \[RFC8751\]](#) states the H-PCE applicability for inter-layer or POI.



[RFC8637] lists various PCEP extensions that apply to ACTN. It also lists the PCEP extension for optical network and POI.

Note that the PCEP can be used in conjunction with the YANG data models described in the rest of this document. Depending on whether ACTN is deployed in a greenfield or brownfield, two options are possible:

1. The MDSC uses a single RESTCONF/YANG interface towards each PNC to discover all the TE information and request TE tunnels. It may either perform full multi-layer path computation or delegate path computation to the underneath PNCs.

This approach is desirable for operators from an multi-vendor integration perspective as it is simple, and we need only one type of interface (RESTCONF) and use the relevant YANG data models depending on the operator use case considered. Benefits of having only one protocol for the MPI between MDSC and PNC have been already highlighted in [[PATH-COMPUTE](#)].

4. The MDSC uses the RESTCONF/YANG interface towards each PNC to discover all the TE information and requests the creation of TE tunnels. However, it uses PCEP for hierarchical path computation.

As mentioned in Option 1, from an operator perspective, this option can add integration complexity to have two protocols instead of one, unless the RESTCONF/YANG interface is added to an existing PCEP deployment (brownfield scenario).

[Section 4](#) and [section 5](#) of this draft analyse the case where a single RESTCONF/YANG interface is deployed at the MPI (i.e., option 1 above).

#### **[4. Inventory, service and network topology discovery](#)**

In this scenario, the MSDC needs to discover through the underlying PNCs:

- o the network topology, at both optical and IP layers, in terms of nodes and links, including the access links, inter-domain IP links as well as cross-layer links;
- o the optical tunnels supporting multi-layer intra-domain IP links;
- o both intra-domain and inter-domain L2/L3 VPN network services deployed within the network;



- o the SR-TE paths supporting those L2/L3 VPN network services;
- o the hardware inventory information of IP and optical equipment.

The O-PNC and P-PNC could discover and report the hardware network inventory information of their equipment that is used by the different management layers. In the context of POI, the inventory information of IP and optical equipment can complement the topology views and facilitate the packet/optical multi-layer view, e.g., by providing a mapping between the lowest level LTPs in the topology view and corresponding physical port in the network inventory view.

The MDSC could also discover the entire network inventory information of both IP and optical equipment and correlate this information with the links reported in the network topology.

Reporting the entire inventory and detailed topology information of packet and optical networks to the MDSC may present, as a potential drawback, scalability issues. The analysis of the scalability of this approach and mechanisms to address potential issues is outside the scope of this document.

Each PNC provides to the MDSC the topology view of the domain it controls, as described in [section 4.1](#) and 4.3. The MDSC uses this information to discover the complete topology view of the multi-layer multi-domain network it controls.

The MDSC should also maintain up-to-date inventory, service and network topology databases of both IP and optical layers through the use of IETF notifications through MPI with the PNCs when any network inventory/topology/service change occurs.

It should be possible also to correlate information coming from IP and optical layers (e.g., which port, lambda/OTSi, and direction, is used by a specific IP service on the WDM equipment).

In particular, for the cross-layer links, it is key for MDSC to automatically correlate the information from the PNC network databases about the physical ports from the routers (single link or bundle links for LAG) to client ports in the ROADM.

The analysis of multi-layer fault management is outside the scope of this document. However, the discovered information should be sufficient for the MDSC to easily correlate optical and IP layers alarms to speed-up troubleshooting.



Alarms and event notifications are required between MDSC and PNCs so that any network changes are reported almost in real-time to the MDSC (e.g., NE or link failure). As specified in [[RFC7923](#)], MDSC must subscribe to specific objects from PNC YANG datastores for notifications.

#### **4.1. Optical topology discovery**

The WSON Topology Model or, alternatively, the Flexi-grid Topology model is used to report the DWDM network topology (e.g., ROADMs nodes and links), depending on whether the DWDM optical network is based on fixed grid or flexible-grid.

The OTN Topology Model is used to report the OTN network topology (e.g., OTN switching nodes and links), when the OTN switching layer is deployed within the optical domain.

In order to allow the MDSC to discover the complete multi-layer and multi-domain network topology and to correlate it with the hardware inventory information, the O-PNCs report an abstract optical network topology where:

- o one TE node is reported for each optical NE deployed within the optical network domain; and
- o one TE link is reported for each OMS link and, optionally, for each OTN link.

The Ethernet Topology Model is used to report the Ethernet client LTPs that terminate the cross-layer links: one Ethernet client LTP is reported for each Ethernet client interface on the optical NEs.

Since the MDSC delegates optical path computation to its underlay O-PNCs, the following information can be abstracted and not reported at the MPI:

- o the optical parameters required for optical path computation, such as those detailed in [[OIA-TOPO](#)];
- o the underlay OTS links and ILAs of OMS links;
- o the physical connectivity between the optical transponders and the ROADMs.

The optical transponders and, optionally, the OTN access cards, are abstracted at MPI by the O-PNC as Trail Termination Points (TTPs),



defined in [[RFC8795](#)], within the optical network topology. This abstraction is valid independently of the fact that optical transponders are physically integrated within the same WDM node or are physically located on a device external to the WDM node since in both cases the optical transponders and the WDM node are under the control of the same O-PNC.

The association between the Ethernet LTPs terminating the Ethernet cross-layer links and the optical TTPs is reported using the Inter Layer Lock (ILL) identifiers, defined in [[RFC8795](#)].

All the optical links are intra-domain and they are discovered by O-PNCs, using mechanisms which are outside the scope of this document, and reported at the MPIs within the optical network topology.

In case of a multi-layer DWDM/OTN network domain, multi-layer intra-domain OTN links are supported by underlay DWDM tunnels, which can be either WSON tunnels or, alternatively, Flexi-grid tunnels, depending on whether the DWDM optical network is based on fixed grid or flexible-grid. This relationship is reported by the mechanisms described in [section 4.2](#).

#### **[4.2. Optical path discovery](#)**

The WSON Tunnel Model or, alternatively, the Flexi-grid Tunnel model, depending on whether the DWDM optical network is based on fixed grid or flexible-grid, is used to report all the DWDM tunnels established within the optical network.

When the OTN switching layer is deployed within the optical domain, the OTN Tunnel Model is used to report all the OTN tunnels established within the optical network.

The Ethernet client signal Model is used to report all the Ethernet connectivity provided by the underlay optical tunnels between Ethernet client LTPs. The underlay optical tunnels can be either DWDM tunnels or, when the optional OTN switching layer is deployed, OTN tunnels.

The DWDM tunnels can be used as underlay tunnels to support either Ethernet client connectivity or multi-layer intra-domain OTN links. In the latter case, the hierarchical-link container, defined in [TE-TUNNEL], is used to reference which multi-layer intra-domain OTN links are supported by the underlay DWDM tunnels.



The O-PNCs report in their operational datastores all the Ethernet client connectivities and all the optical tunnels deployed within their optical domain regardless of the mechanisms being used to set them up, such as the mechanisms described in [section 5.2](#), as well as other mechanism (e.g., static configuration), which are outside the scope of this document.

#### **[4.3. Packet topology discovery](#)**

The L3 Topology Model, SR Topology Model, TE Topology Model and the TE Packet Topology Model are used together to report the SR-TE network topology, as described in figure 2 of [\[SR-TE-TOPO\]](#).

In order to allow the MDSC to discover the complete multi-layer and multi-domain network topology and to correlate it with the hardware inventory information as well as to perform multi-domain SR-TE path computation, the P-PNCs report the full SR-TE network, including all the information that is required by the MDSC to perform SR-TE path computation. In particular, one TE node is reported for each router and one TE link is reported for each intra-domain IP link. The SR-TE topology also reports the IP LTPs terminating the inter-domain IP links.

All the intra-domain IP links are discovered by the P-PNCs, using mechanisms, such as LLDP [IEEE 802.1AB], which are outside the scope of this document, and reported at the MPIs within the SR-TE network topology.

The Ethernet Topology Model is used to report the intra-domain Ethernet links supporting the intra-domain IP links as well as the Ethernet LTPs that might terminate cross-layer links, inter-domain Ethernet links or access links, as described in detail in [section 4.5](#) and in [section 4.6](#).

#### **[4.4. SR-TE path discovery](#)**

This version of the draft assumes that discovery of existing SR-TE paths, including their bandwidth, at the MPI is done using the generic TE tunnel YANG data model, defined in [\[TE-TUNNEL\]](#), with SR-TE specific augmentations, as outlined in section 1 of [\[TE-TUNNEL\]](#).

Note that technology-specific augmentations of the generic path TE tunnel model for SR-TE path setup and discovery have been identified as a gap.



To enable MDSC to discover the full end-to-end SR-TE path configuration, the SR-TE specific augmentation of the [[TE-TUNNEL](#)] should allow the P-PNC to report the SID list assigned to an SR-TE path within its domain.

For example, considering the L3VPN in Figure 2, the PE13-P16-PE14 SR-TE path and the SR-TE path in the reverse direction (between PE14 and PE13) could be reported by the P-PNC1 to the MDSC as TE paths of the same TE tunnel instance. The bandwidth of these TE paths represents the bandwidth allocated by P-PNC1 to the two SR-TE paths, which can be symmetric or asymmetric in the two directions.

The P-PNCs use the TE tunnel model to report, at the MPI, all the SR-TE paths established within their packet domain regardless of the mechanism being used to set them up. In other words, the TE tunnel data model reports within the operational datastore both the SR-TE paths being setup by the MDSC at the MPI, using the mechanisms described in [section 5.3](#), as well as the SR-TE paths being setup by other means, such as static configuration, which are outside the scope of this document.

#### **[4.5. Inter-domain link discovery](#)**

In the reference network of Figure 1, there are three types of inter-domain links:

- o Inter-domain Ethernet links supporting inter-domain IP links between two adjacent IP domains;
- o Cross-layer links between an IP domain and an adjacent optical domain;
- o Access links between a CE device and a PE router.

All the three types of links are Ethernet links.

It is worth noting that the P-PNC may not be aware whether an Ethernet interface terminates a cross-layer link, an inter-domain Ethernet link or an access link.

It is not yet clarified which model can be used to report the access links between CEs and PEs (e.g., by using the Ethernet Topology Model defined in [[CLIENT-TOPO](#)] or by using the SAP Model defined in [[SAP](#)]). This has been identified as a gap.



The inter-domain Ethernet links and cross-layer links are discovered by the MDSC using the plug-id attribute, as described in [section 4.3 of \[RFC8795\]](#).

More detailed description of how the plug-id can be used to discover inter-domain links is also provided in section 5.1.4 of [\[TNBI\]](#).

This document considers the following two options for discovering inter-domain links:

1. Static configuration
2. LLDP [IEEE 802.1AB] automatic discovery

Other options are possible but not described in this document.

As outlined in [\[TNBI\]](#), the encoding of the plug-id namespace and the specific LLDP information reported within the plug-id value, such as the Chassis ID and Port ID mandatory TLVs, is implementation specific and needs to be consistent across all the PNCs within the network.

The static configuration requires an administrative burden to configure network-wide unique identifiers: it is therefore more viable for inter-domain Ethernet links. For the cross-layer links, the automatic discovery solution based on LLDP snooping is preferable when possible.

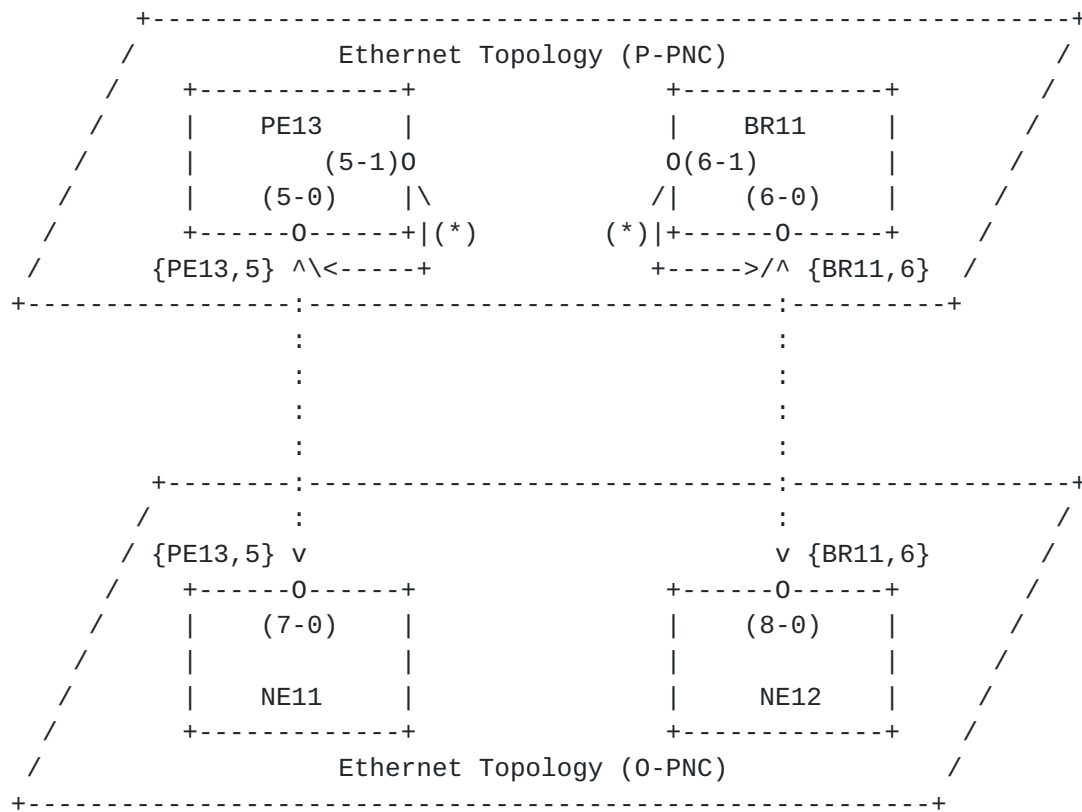
The routers exchange standard LLDP packets as defined in [IEEE 802.1AB] and the optical NEs snoop the LLDP packets received from the local Ethernet interface and report to the O-PNCs the extracted information, such as the Chassis ID, the Port ID, System Name TLVs.

Note that the optical NEs do not actively participate in the LLDP packet exchange and does not send any LLDP packets.

#### **[4.5.1. Cross-layer link discovery](#)**

The MDSC can discover a cross-layer link by matching the plug-id values of the two Ethernet LTPs reported by two adjacent O-PNC and P-PNC: in case LLDP snooping is used, the P-PNC reports the LLDP information sent by the corresponding Ethernet interface on the router while the O-PNC reports the LLDP information received by the corresponding Ethernet interface on the optical NE, e.g., between LTP 5-0 on PE13 and LTP 7-0 on NE11, as shown in Figure 4.





## Notes:

=====

(\*) Supporting LTP

## Legenda:

=====

0 LTP

----&gt; Supporting LTP

&lt;...&gt; Link discovered by the MDSC

{ } LTP Plug-id reported by the PNC

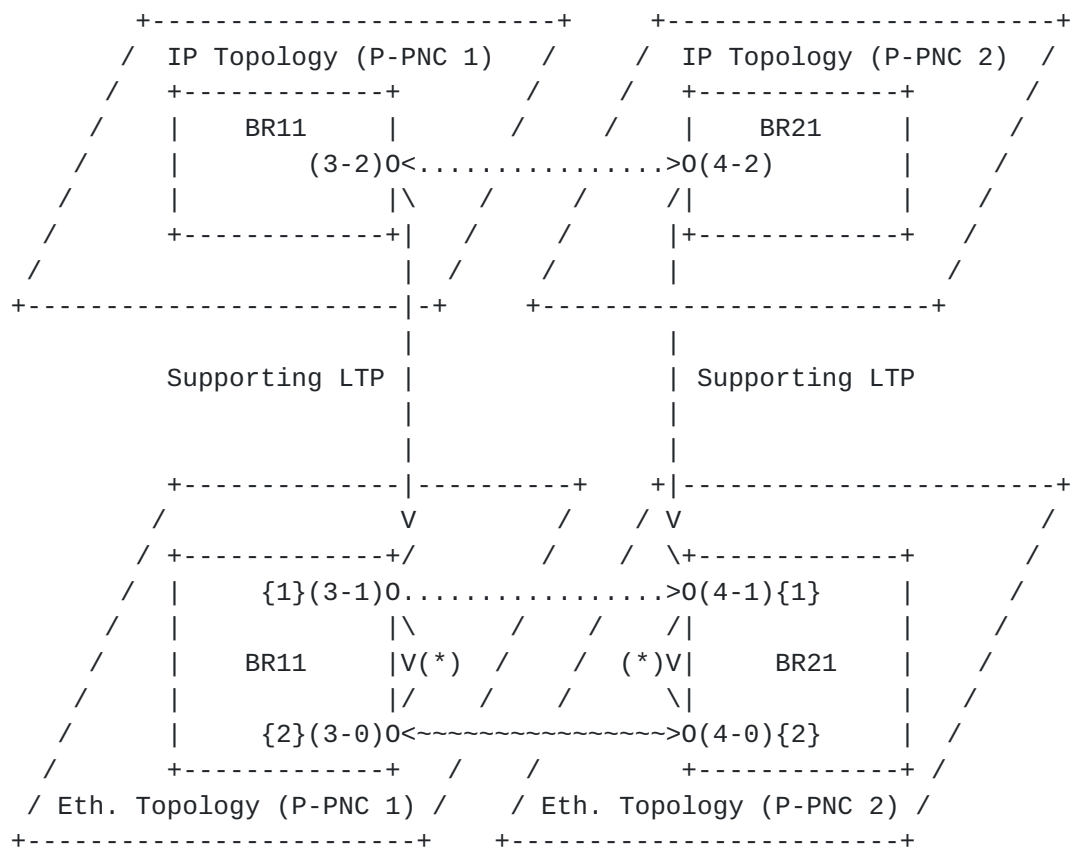
Figure 4 - Cross-layer link discovery

It is worth noting that the discovery of cross-layer links is based only on the LLDP information sent by the Ethernet interfaces of the routers and received by the Ethernet interfaces of the optical NEs, Therefore the MDSC can discover these links also before overlay multi-layer IP links are setup.



#### **4.5.2. Inter-domain IP link discovery**

The MDSC can discover an inter-domain Ethernet link which supports an inter-domain IP link, by matching the plug-id values of the two Ethernet LTPs reported by the two adjacent P-PNCs: the two P-PNCs report the LLDP information being sent and being received from the corresponding Ethernet interfaces, e.g., between the Ethernet LTP 3-1 on BR11 and the Ethernet LTP 4-1 on BR21 shown in Figure 5.



## Notes:

=====

(\*) Supporting LTP

{1} {BR11,3, BR21,4}

{2} {BR11,3}

## Legenda:

=====

0 LTP

----&gt; Supporting LTP

&lt;...&gt; Link discovered by the MDSC

&lt;~~~&gt; Link inferred by the MDSC

{ } LTP Plug-id reported by the PNC

Figure 5 - Inter-domain Ethernet and IP link discovery

Different information is required to be encoded within the plug-id attribute of the Ethernet LTPs to discover cross-layer links and inter-domain Ethernet links.



If the P-PNC does not know a priori whether an Ethernet interface on a router terminates a cross-layer link or an inter-domain Ethernet link, it has to report at the MPI two Ethernet LTPs representing the same Ethernet interface, e.g., both the Ethernet LTP 3-0 and the Ethernet LTP 3-1, supported by LTP 3-0, shown in Figure 5:

- o The physical Ethernet LTP is used to represent the physical adjacency between the router Ethernet interface and either the adjacent router Ethernet interface (in case of a single-layer Ethernet link) or the optical NE Ethernet interface (in case of a multi-layer Ethernet link). Therefore, this LTP reports, within the plug-id attribute, the LLDP information sent by the corresponding router Ethernet interface;
- o The logical Ethernet LTP, supported by a physical Ethernet LTP, is used to discover the logical adjacency between router Ethernet interfaces, which can be either single-layer or multi-layer. Therefore, this LTP reports, within the plug-id attribute, the LLDP information sent and received by the corresponding router Ethernet interface.

It is worth noting that in case of an inter-domain single-layer Ethernet link, the physical adjacency between the two router Ethernet interfaces cannot be discovered by the MDSC, using the LLDP information reported in the plug-id attributes, as shown in Figure 5. However, the MDSC may infer these links if it knows a priori, using mechanisms which are outside the scope of this document, that inter-domain Ethernet links are always single-layer, e.g., as shown in Figure 5.

The P-PNC can omit reporting the physical Ethernet LTPs when it knows, by mechanisms which are outside the scope of this document, that the corresponding router Ethernet interfaces terminate single-layer inter-domain Ethernet links.

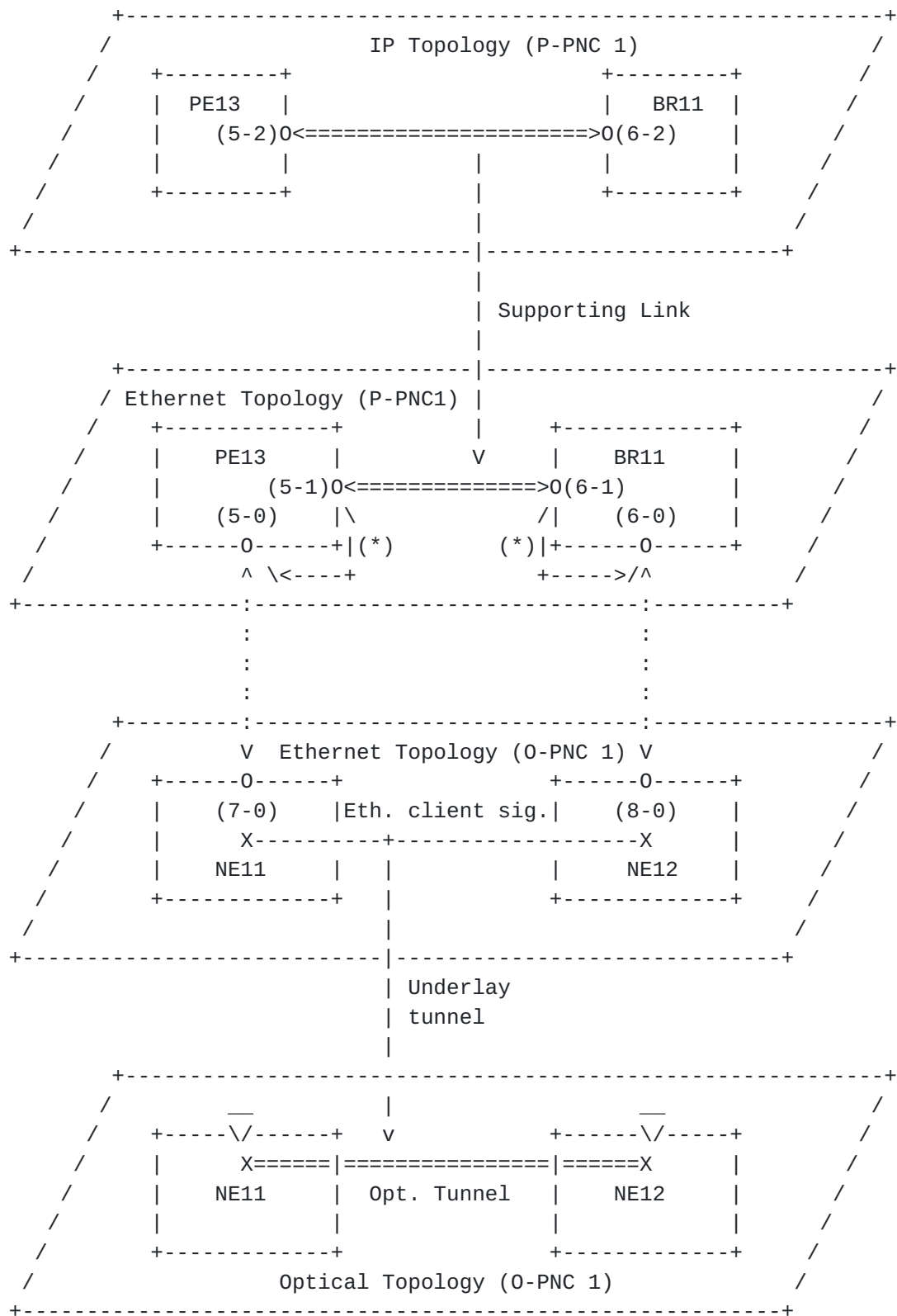
The MDSC can then discover an inter-domain IP link between the two IP LTPs that are supported by the two Ethernet LTPs terminating an inter-domain Ethernet link, discovered as described in [section 4.5.2](#), e.g., between the IP LTP 3-2 on BR21 and the IP LTP 4-2 on BR22, supported respectively by the Ethernet LTP 3-1 on BR11 and by the Ethernet LTP 4-1 on BR21, as shown in Figure 5.

#### **4.6. Multi-layer IP link discovery**

A multi-layer intra-domain IP link and its supporting multi-layer intra-domain Ethernet link are discovered by the P-PNC like any other



intra-domain IP and Ethernet links, as described in [section 4.3](#), and reported at the MPI within the SR-TE and Ethernet network topologies, e.g., as shown in Figure 6.





Notes:

=====

(\*) Supporting LTP

Legenda:

=====

0 LTP

----> Supporting LTP or Supporting Link or Underlay tunnel

<====> Link discovered by the PNC and reported at the MPI

<...> Link discovered by the MDSC

<~~~> Link inferred by the MDSC

x---x Ethernet client signal

X===X Optical tunnel

Figure 6 - Multi-layer intra-domain Ethernet and IP link discovery

The P-PNC does not report any plug-id information on the Ethernet LTPs terminating intra-domain Ethernet links since these links are discovered by the PNC.

In addition, the P-PNC also reports the physical Ethernet LTPs that terminate the cross-layer links supporting the multi-layer intra-domain Ethernet links, e.g., the Ethernet LTP 5-0 on PE13 and the Ethernet LTP 6-0 on BR11, shown in Figure 6.

The MDSC discovers, using the mechanisms described in [section 4.5](#), which Ethernet cross-layer links support the multi-layer intra-domain Ethernet links, e.g. as shown in Figure 6.

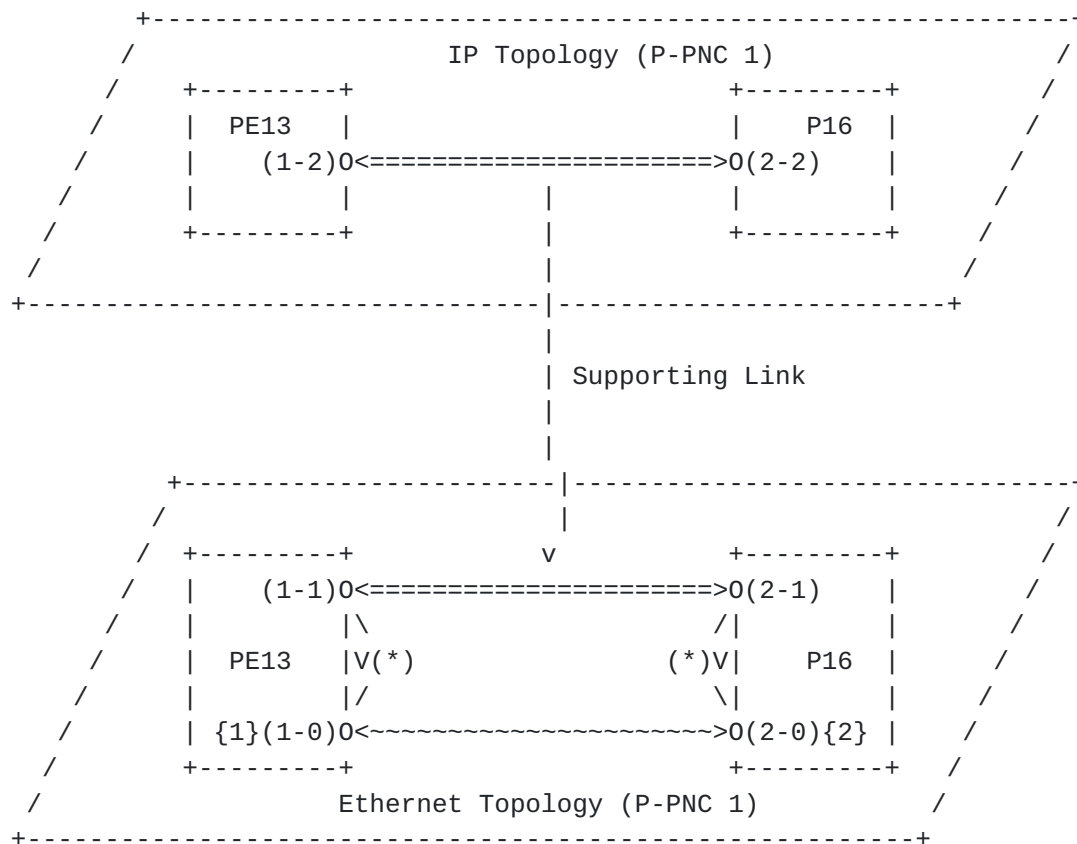
The MDSC also discovers, from the information provided by the O-PNC and described in [section 4.2](#), which optical tunnels support the multi-layer intra-domain IP links and therefore the path within the optical network that supports a multi-layer intra-domain IP link, e.g., as shown in Figure 6.

#### **[4.6.1](#). Single-layer intra-domain IP links**

It is worth noting that the P-PNC may not be aware of whether an Ethernet interface on the router terminates a multi-layer or a single-layer intra-domain Ethernet link.

In this case, the P-PNC, always reports two Ethernet LTPs for each Ethernet interface on the router, e.g., the Ethernet LTP 1-0 and 1-1 on PE13, shown in Figure 7.





## Notes:

=====

(\*) Supporting LTP

{1} {PE13,1}

{2} {P16,2}

## Legenda:

=====

0 LTP

----&gt; Supporting LTP

&lt;====&gt; Link discovered by the PNC and reported at the MPI

&lt;~~~~&gt; Link inferred by the MDSC

{ } LTP Plug-id reported by the PNC

Figure 7 - Single-layer intra-domain Ethernet and IP link discovery

In this case, the MDSC, using the plug-id information reported in the physical Ethernet LTPs, does not discover any cross-layer link being terminated by the corresponding Ethernet interface. The MDSC may infer the physical intra-domain Ethernet link, e.g., between LTP 1-0 on PE13 and LTP 2-0 on P16, as shown in Figure 7, if it knows a



priori, by mechanisms which are outside the scope of this document, that all the Ethernet interfaces on the routers either terminates a cross-layer link or a single-layer intra-domain Ethernet link.

The P-PNC can omit reporting the physical Ethernet LTP if it knows, by mechanisms which are outside the scope of this document, that the intra-domain Ethernet link is single-layer.

#### **4.7. LAG discovery**

TBA

#### **4.8. L2/L3 VPN network services discovery**

TBA

#### **4.9. Inventory discovery**

There are no YANG data models in IETF that could be used to report at the MPI the whole inventory information discovered by a PNC.

[RFC8345] had foreseen some work for inventory as an augmentation of the network model, but no YANG data model has been developed so far.

There are also no YANG data models in IETF that could be used to correlate topology information, e.g., a link termination point (LTP), with inventory information, e.g., the physical port supporting an LTP, if any.

Inventory information through MPI and correlation with topology information is identified as a gap requiring further work and outside of the scope of this draft.

### **5. Establishment of L2/L3 VPN network services with TE requirements**

In this scenario the MDSC needs to setup a multi-domain L2VPN or a multi-domain L3VPN with some SLA requirements.

The MDSC receives the request to setup a L2/L3 VPN network service from the OSS/Orchestration layer (see [Appendix A](#)).

The MDSC translates the L2/L3 VPN SLA requirements into TE requirements (e.g., bandwidth, TE metric bounds, SRLG disjointness, nodes/links/domains inclusion/exclusion) and find the SR-TE paths that meet these TE requirements (see [section 2.1.1](#)).



For example, considering the L3VPN in Figure 2, the MDSC finds that:

- o a PE13-P16-PE14 SR-TE path already exists but have not enough bandwidth to support the new L3VPN, as described in [section 4.4](#);
- o the IP link(s) between P16 and PE14 has not enough bandwidth to support increasing the bandwidth of that SR-TE path, as described in [section 4.3](#);
- o a new underlay optical tunnel could be setup to increase the bandwidth IP link(s) between P16 and PE14 to support increasing the bandwidth of that overlay SR-TE path, as described in [section 5.2](#). The dimensioning of the underlay optical tunnel is decided by the MDSC based on the bandwidth requested by the SR-TE path and on its multi-layer optimization policy, which is an internal MDSC implementation issue.

Considering for example the L3VPN in Figure 2, the MDSC can also decide that a new multi-domain SR-TE path needs to be setup between PE13 and PE23, e.g., either because existing SR-TE paths between PE13 and PE23 are not able to meet the TE and binding requirements of the L2/L3 VPN service or because there is no SR-TE path between PE13 and PE23.

As described in [section 2.1.2](#), with partial summarization, the MDSC will use the TE topology information provided by the P-PNCs and the results of the path computation requests sent to the O-PNCs, as described in [section 5.1](#), to compute the multi-layer/multi-domain path between PE13 and PE23.

For example, the multi-layer/multi-domain performed by the MDSC could require the setup of:

- o a new underlay optical tunnel between PE13 and BR11, supporting a new IP link, as described in [section 5.2](#);
- o a new underlay optical tunnel between BR21 and P24 to increase the bandwidth of the IP link(s) between BR21 and P24, as described in [section 5.2](#).

When the setup of the L2/L3 VPN network service requires multi-domain and multi-layer coordination, the MDSC is also responsible for coordinating the network configuration required to realize the request network service across the appropriate optical and packet domains.



The MDSC would therefore request:

- o the O-PNC1 to setup a new optical tunnel between the ROADMs connected to P16 and PE14, as described in [section 5.2](#);
- o the P-PNC1 to update the configuration of the existing IP link, in case of LAG, or configure a new IP link, in case of ECMP, between P16 and PE14, as described in [section 5.2](#);
- o the P-PNC1 to update the bandwidth of the selected SR-TE path between PE13 and PE14, as described in [section 5.3](#).

After that, the MDSC requests P-PNC2 to setup an SR-TE path between BR21 and PE23, with an explicit path (BR21, P24, PE23) to constraint this new SR-TE path to use the new underlay optical tunnel setup between BR21 and P24, as described in [section 5.3](#). The P-PNC2, knowing the node and the adjacency SIDs assigned within its domain, can install the proper SR policy, or hierarchical policies, within BR21 and returns to the MDSC the binding SID it has assigned to this policy in BR21.

Then the MDSC requests P-PNC1 to setup an SR-TE path between PE13 and BR11, with an explicit path (PE13, BR11) to constraint this new SR-TE path to use the new underlay optical tunnel setup between PE13 and BR11, specifying also which inter-domain link should be used to send traffic to BR21 and the binding SID that has been assigned by P-PNC2 to the corresponding SR policy in BR21, to be used for the end-to-end SR-TE path stitching, as described in [section 5.3](#). The P-PNC1, knowing also the node and the adjacency SIDs assigned within its domain and the EPE SID assigned by P-PNC1 to the inter-domain link between BR11 and BR21, and the binding SID assigned by P-PNC2, installs the proper policy, or policies, within PE13.

Once the SR-TE paths have been selected and, if needed, setup/modified, the MDSC can request to both P-PNCs to configure the L3VPN and its binding with the selected SR-TE paths using the [\[RFC9182\]](#) and [\[TSM\]](#) YANG data models.

[Editor's Note] Further investigation is needed to understand how the binding between a L3VPN and this new end-to-end SR-TE path can be configured.

### **[5.1. Optical Path Computation](#)**

As described in [section 2.1.2](#), the optical path computation is usually performed by the O-PNCs.



When performing multi-layer/multi-domain path computation, the MDSC can delegate the O-PNC for single-domain optical path computation.

As discussed in [[PATH-COMPUTE](#)], there are two options to request an O-PNC to perform optical path computation: either via a "compute-only" TE tunnel path, using the generic TE tunnel YANG data model defined in [[TE-TUNNEL](#)] or via the path computation RPC defined in [[PATH-COMPUTE](#)].

This draft assumes that the path computation RPC is used.

As described in sections [4.1](#) and [4.5](#), there is a one-to-one relationship between the router ports, the cross-layer links and the optical TTPs. Therefore, the properties of an optical path between two optical TTPs, as computed by the O-PNC, can be used by the MDSC to infer the properties of the multi-layer single-domain IP link between the router ports associated with the two optical TTPs.

There are no YANG data models in IETF that could be used to augment the generic path computation RPC with technology-specific attributes.

Optical technology-specific augmentation for the path computation RPC is identified as a gap requiring further work outside of this draft's scope.

## **[5.2. Multi-layer IP link Setup](#)**

To setup a new multi-layer IP link between two router ports, the MDSC requires the O-PNC to setup an optical tunnel (either a WSON Tunnel or a Flexi-grid Tunnel or an OTN Tunnel) within the optical network between the two TTPs associated, as described in [section 5.1](#), with these two router Ethernet interfaces.

The MDSC also requires the O-PNC to steer the Ethernet client traffic between the two cross-layer links over the optical tunnel using the Ethernet Client Signal Model.

After the optical tunnel has been setup and the client traffic steering configured, the two IP routers can exchange Ethernet packets between themselves, including LLDP messages.

If LLDP [IEEE 802.1AB] or any other discovery mechanisms, which are outside the scope of this document, is used between the adjacency between the two routers' ports, the P-PNC can automatically discover the underlay multi-layer single-domain Ethernet link being set up by the MDSC and report it to the P-PNC.



Otherwise, if there are no automatic discovery mechanisms, the MDSC can configure this multi-layer single-domain Ethernet link at the MPI of the P-PNC.

The two Ethernet LTPs terminating this multi-layer single-domain Ethernet link are supported by the two underlay Ethernet LTPs terminating the two cross-layer links, e.g., as shown in Figure 6.

After the multi-layer single-domain Ethernet link has been configured, the corresponding multi-layer single-domain IP link can also be configured either by the MDSC or by the P-PNC.

This document assumes that this IP link is configured by the P-PNC, when the underlying multi-layer single-domain Ethernet link is either discovered by the P-PNC or configured by the MDSC at the MPI.

[Editor's Note] Add text for IP link update in case of LAG either here or in a new section.

[Editor's Note] Add text about the configuration of multi-layer SRLG information (issue #45).

It is worth noting that the list of SRLGs for a multi-layer IP link can be quite long. Implementation-specific mechanisms can be implemented by the MDSC or by the P-PNC to summarize the SRLGs of an optical tunnel. These mechanisms are implementation-specific and have no impact on the YANG models nor on the interoperability at the MPI, but care has to be taken to avoid missing information.

### **5.3. SR-TE Path Setup and Update**

This version of the draft assumes that SR-TE path setup and update at the MPI could be done using the generic TE tunnel YANG data model, defined in [TE-TUNNEL], with SR-TE specific augmentations, as also outlined in section 1 of [TE-TUNNEL].

When a new SR-TE path needs to be setup, the MDSC can use the [TE-TUNNEL] model to request the P-PNC to setup TE paths, properly specifying the path constraints, such as the explicit path, to force the P-PNC to setup an SR-TE path that meets the end-to-end TE and bidding constraints and uses the optical tunnels setup by the MDSC for the purpose of supporting this new SR-TE path.

The [TE-TUNNEL] model supports requesting the setup of both end-to-end as well as segment TE tunnels (within one domain).



In the latter case, SR-TE specific augmentations of the [\[TE-TUNNEL\]](#) model should be defined to allow the MDSC to configure the binding SIDs to be used for the end to-end SR-TE path stitching and to allow the P-PNC to report the binding SID assigned to the segment TE paths.

The assigned binding SID should be persistent in case router or P-PNC rebooting.

The MDSC can also use the [\[TE-TUNNEL\]](#) model to request the P-PNC to increase the bandwidth allocated to an existing TE path, and, if needed, also on its reverse TE path. The [\[TE-TUNNEL\]](#) model supports both symmetric and asymmetric bandwidth configuration in the two directions.

[Editor's Note:] Add some text about the protection options (to further discuss whether to put this text here or in [section 4.2.2](#)).

The MDSC also request the P-PNC to configure TI-LFA local protection: the mechanisms to request the configuration TI-LFA local protection for SR-TE paths using the [\[TE-TUNNEL\]](#) are a gap in the current YANG models.

The TI-LFA local protection within the P-PNC domain is configured by the P-PNC through implementation specific mechanisms which are outside the scope of this document. The P-PNC takes into account the multi-layer SRLG information, configured by the MDSC as described in [section 5.2](#), when computing the TI-LFA post-convergence path for multi-layer single-domain IP links.

SR-TE path setup and update (e.g., bandwidth increase) through MPI is identified as a gap requiring further work, which is outside of the scope of this draft.

## **6. Conclusions**

The analysis provided in this document has shown that the IETF YANG models described in 3.2 provides useful support for Packet Optical Integration (POI) scenarios for resource discovery (network topology, service, tunnels and network inventory discovery) as well as for supporting multi-layer/multi-domain L2/L3 VPN network services.

Few gaps have been identified to be addressed by the relevant IETF Working Groups:



- o network inventory model: this gap has been identified in [section 4.9](#) and the solution in [[NETWORK-INVENTORY](#)] has been proposed to resolve it;
- o technology-specific augmentations of the path computation RPC, defined in [[PATH-COMPUTE](#)] for optical networks: this gap has been identified in [section 5.1](#) and the solution in [[OPTICAL-PATH-COMPUTE](#)] has been proposed to resolve it;
- o relationship between a common discovery mechanisms applicable to access links, inter-domain IP links and cross-layer links and the UNI topology discover mechanism defined in [[SAP](#)]: this gap has been identified in [section 4.3](#);
- o a mechanism applicable to the P-PNC NBI to configure the SR-TE paths. Technology-specific augmentations of TE Tunnel model, defined in [[TE-TUNNEL](#)], are foreseen in section 1 of [[TE-TUNNEL](#)] but not yet defined: this gap has been identified in [section 5.3](#).

## **[7. Security Considerations](#)**

Several security considerations have been identified and will be discussed in future versions of this document.

## **[8. Operational Considerations](#)**

Telemetry data, such as collecting lower-layer networking health and consideration of network and service performance from POI domain controllers, may be required. These requirements and capabilities will be discussed in future versions of this document.

## **[9. IANA Considerations](#)**

This document requires no IANA actions.

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## **Appendix A. OSS/Orchestration Layer**

The OSS/Orchestration layer is a vital part of the architecture framework for a service provider:

- o to abstract (through MDSC and PNCs) the underlying transport network complexity to the Business Systems Support layer;
- o to coordinate NFV, Transport (e.g. IP, optical and microwave networks), Fixed Access, Core and Radio domains enabling full automation of end-to-end services to the end customers;
- o to enable catalogue-driven service provisioning from external applications (e.g. Customer Portal for Enterprise Business services), orchestrating the design and lifecycle management of these end-to-end transport connectivity services, consuming IP and/or optical transport connectivity services upon request.

As discussed in [section 2.1](#), in this document, the MDSC interfaces with the OSS/Orchestration layer and, therefore, it performs the functions of the Network Orchestrator, defined in [\[RFC8309\]](#).

The OSS/Orchestration layer requests the creation of a network service to the MDSC specifying its end-points (PEs and the interfaces towards the CEs) as well as the network service SLA and then proceeds to configuring accordingly the end-to-end customer service between the CEs in the case of an operator managed service.

### **A.1. MDSC NBI**

As explained in [section 2](#), the OSS/Orchestration layer can request the MDSC to setup L2/L3VPN network services (with or without TE requirements).

Although the OSS/Orchestration layer interface is usually operator-specific, typically it would be using a RESTCONF/YANG interface with a more abstracted version of the MPI YANG data models used for network configuration (e.g. L3NM, L2NM).

Figure 8 shows an example of possible control flow between the OSS/Orchestration layer and the MDSC to instantiate L2/L3 VPN network services, using the YANG data models under the definition in [\[VN\]](#), [\[L2NM\]](#), [\[RFC9182\]](#) and [\[TSM\]](#).



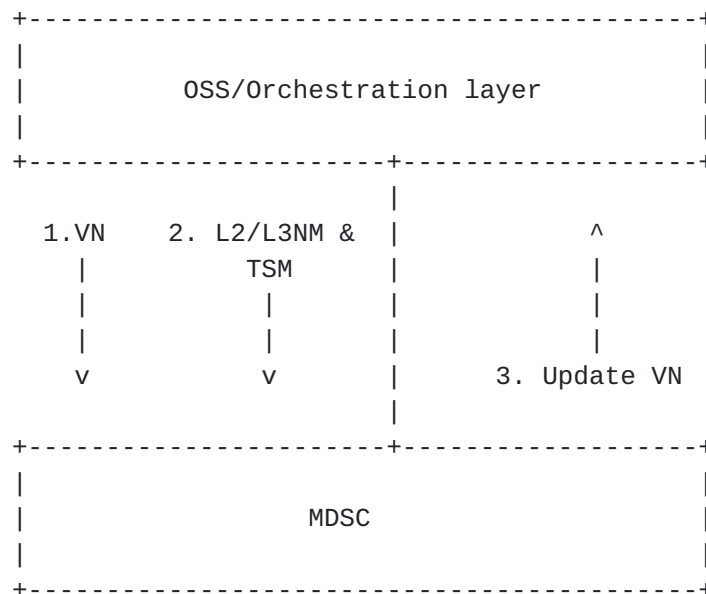


Figure 8 Service Request Process

- o The VN YANG data model, defined in [VN], whose primary focus is the CMI, can also provide VN Service configuration from an orchestrated network service point of view when the L2/L3 VPN network service has TE requirements. However, this model is not used to setup L2/L3 VPN service with no TE requirements.
- o It provides the profile of VN in terms of VN members, each of which corresponds to an edge-to-edge link between customer end-points (VNAPs). It also provides the mappings between the VNAPs with the LTPs and the connectivity matrix with the VN member. The associated traffic matrix (e.g., bandwidth, latency, protection level, etc.) of VN member is expressed (i.e., via the TE-topology's connectivity matrix).
- o The model also provides VN-level preference information (e.g., VN member diversity) and VN-level admin-status and operational-status.
- o The L2NM and L3NM YANG data models, defined in [L2NM] and [RFC9182], whose primary focus is the MPI, can also be used to provide L2VPN and L3VPN network service configuration from a orchestrated connectivity service point of view.
- o The TE & Service Mapping YANG data model [TSM] provides TE-service mapping.



- o TE-service mapping provides the mapping between a L2/L3 VPN instance and the corresponding VN instances.
- o The TE-service mapping also provides the binding requirements as to how each L2/L3 VPN/VN instance is created concerning the underlay TE tunnels (e.g., whether they require a new and isolated set of TE underlay tunnels or not).
- o Site mapping provides the site reference information across L2/L3 VPN Site ID, VN Access Point ID, and the LTP of the access link.

## **Appendix B. Multi-layer and multi-domain resiliency**

### **B.1. Maintenance Window**

Before planned maintenance operation on DWDM network takes place, IP traffic should be moved hitless to another link.

MDSC must reroute IP traffic before the events takes place. It should be possible to lock IP traffic to the protection route until the maintenance event is finished, unless a fault occurs on such path.

### **B.2. Router port failure**

The focus is on client-side protection scheme between IP router and reconfigurable ROADM. Scenario here is to define only one port in the routers and in the ROADM muxponder board at both ends as back-up ports to recover any other port failure on client-side of the ROADM (either on router port side or on muxponder side or on the link between them). When client-side port failure occurs, alarms are raised to MDSC by IP-PNC and O-PNC (port status down, LOS etc.). MDSC checks with OP-PNC(s) that there is no optical failure in the optical layer.

There can be two cases here:

- a) LAG was defined between the two end routers. MDSC, after checking that optical layer is fine between the two end ROADMs, triggers the ROADM configuration so that the router back-up port with its associated muxponder port can reuse the OCh that was already in use previously by the failed router port and adds the new link to the LAG on the failure side.

While the ROADM reconfiguration takes place, IP/MPLS traffic is using the reduced bandwidth of the IP link bundle, discarding lower priority traffic if required. Once back-up port has been reconfigured to reuse the existing OCh and new link has been added to the LAG then original Bandwidth is recovered between the end routers.

Note: in this LAG scenario let assume that BFD is running at LAG level so that there is nothing triggered at MPLS level when one of the link member of the LAG fails.



- b) If there is no LAG then the scenario is not clear since a router port failure would automatically trigger (through BFD failure) first a sub-50ms protection at MPLS level :FRR (MPLS RSVP-TE case) or TI-LFA (MPLS based SR-TE case) through a protection port. At the same time MDSC, after checking that optical network connection is still fine, would trigger the reconfiguration of the back-up port of the router and of the ROADM muxponder to re-use the same OCh as the one used originally for the failed router port. Once everything has been correctly configured, MDSC Global PCE could suggest to the operator to trigger a possible re-optimization of the back-up MPLS path to go back to the MPLS primary path through the back-up port of the router and the original OCh if overall cost, latency etc. is improved. However, in this scenario, there is a need for protection port PLUS back-up port in the router which does not lead to clear port savings.

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#### Contributors

Sergio Belotti  
Nokia

Email: sergio.belotti@nokia.com

Gabriele Galimberti  
Cisco

Email: ggalimbe@cisco.com

Zheng Yanlei  
China Unicom

Email: zhengyanlei@chinaunicom.cn

Anton Snitser  
Sedona

Email: antons@sedonasys.com

Washington Costa Pereira Correia  
TIM Brasil

Email: wcorreia@timbrasil.com.br

Michael Scharf  
Hochschule Esslingen - University of Applied Sciences

Email: michael.scharf@hs-esslingen.de

Young Lee  
Sung Kyun Kwan University

Email: younglee.tx@gmail.com

Jeff Tantsura  
Apstra

Email: jefftant.ietf@gmail.com

Paolo Volpato  
Huawei

Email: paolo.volpato@huawei.com

Brent Foster  
Cisco

Email: brfoster@cisco.com

Authors' Addresses

Fabio Peruzzini  
TIM

Email: fabio.peruzzini@telecomitalia.it

Jean-Francois Bouquier  
Vodafone

Email: jeff.bouquier@vodafone.com

Italo Busi  
Huawei

Email: Italo.busi@huawei.com

Daniel King  
Old Dog Consulting

Email: daniel@olddog.co.uk

Daniele Ceccarelli  
Ericsson

Email: daniele.ceccarelli@ericsson.com