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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# 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. Thus allowing a wide range of transport connectivity 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), 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 network. 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 maintenance events).

ACTN framework enables this complete multi-layer and multi-vendor integration of packet and optical networks through MDSC and packet and optical PNCs.

In this document, critical scenarios for POI are described from the packet service layer perspective and identify 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.

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

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

# Reference architecture and network scenario

This document analyses several deployment scenarios for Packet and Optical Integration (POI) in which ACTN hierarchy is deployed to control a multi‑layer and multi-domain network, with two Optical domains and two Packet domains, as shown in Figure 1:

+----------+

| MDSC |

+-----+----+

|

+-----------+-----+------+-----------+

| | | |

+----+----+ +----+----+ +----+----+ +----+----+

| P-PNC 1 | | O-PNC 1 | | O-PNC 2 | | P-PNC 2 |

+----+----+ +----+----+ +----+----+ +----+----+

| | | |

| \ / |

+-------------------+ \ / +-------------------+

CE1 / PE1 BR1 \ | / / BR2 PE2 \ CE2

o--/---o o---\-|-------|--/---o o---\--o

\ : : / | | \ : : /

\ : PKT Domain 1 : / | | \ : PKT Domain 2 : /

+-:---------------:-+ | | +-:---------------:--+

: : | | : :

: : | | : :

+-:---------------:------+ +-------:---------------:--+

/ : : \ / : : \

/ o...............o \ / o...............o \

\ Optical Domain 1 / \ Optical Domain 2 /

\ / \ /

+------------------------+ +--------------------------+

1. – Reference Scenario

The ACTN architecture, defined in [RFC8453], is used to control this multi-domain network where each Packet PNC (P-PNC) is responsible for controlling its packet domain, which can be either an Autonomous System (AS), [RFC1930], or an IGP area within the same operator network. Each Optical PNC (O-PNC) in the above topology is responsible for controlling its optical domain.

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 a 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 network scenario of Figure 1, it is assumed that:

* 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;
* Inter-domain links exist only between packet domains (i.e., between BRs) and between packet and optical domains (i.e., between routers and optical NEs). In other words, there are no inter-domain links between optical domains;
  + The interfaces between the routers and the optical NEs are Ethernet physical interfaces;
  + The interfaces between the Border Routers (BRs) are Ethernet physical interfaces.

allows rpoptical The analysis of theis outside the scope of this draft

This document analyses scenarios where 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, or intra‑domain BR‑BR IP links. Therefore the inter-domain IP links are supported only by an Ethernet physical links.

The analysis of scenarios with multi-layer inter/domain (inter-AS/inter-area) IP links (e.g., inter‑domain BR-BR or PE-PE IP links), supported by optical network, 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 NEs within the optical domains can be ROADMs or OTN switches, with or without an integrated ROADM function.

## Multi‑domain Service Coordinator (MDSC) functions

The MDSC in Figure 1is responsible for multi-domain and multi-layer coordination across multiple Packet and Optical domains, as well as to provide multi-layer/multi-domain L2/L3VPN 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‑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 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 MDSC multi-layer coordination is initiated:

* Initiated by a request from the OSS/Orchestration layer to setup L2/L3 VPN network services that requires multi-layer/multi-domain coordination;
* 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.

### L2/L3 VPN network service setup



The MDSC receives the request to setup a L2/L3 VPN network service from the OSS/Orchestration layer.

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

In this case, one of the key MDSC functions is to identify the underlay multi‑domain/multi-layer paths used to carry the L2/L3 VPN traffic 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‑domai/multi-layer paths.

TE binding requirement types [TSM] are:

1. Hard Isolation with deterministic latency: The L2/L3VPN service requires a set of dedicated TE Tunnels providing deterministic latency performances and that cannot be not shared with other services, nor compete for bandwidth with other Tunnels.
2. Hard Isolation: This is similar to the above case without deterministic latency requirements.
3. Soft Isolation: The L2/L3VPN service requires a set of dedicated MPLS-TE tunnels that cannot be shared with other services, but which could compete for bandwidth with other Tunnels.
4. Sharing: The L2/L3VPN service allows sharing the MPLS-TE Tunnels supporting it with other services.

There could be additional TE binding requirements for the first three types with respect to different VN members of the same VN (on how different VN members, belonging to the same VN, can share or not network resources). For the first two cases, VN members can be hard‑isolated, soft-isolated, or shared. For the third case, VN members can be soft-isolated or shared.

***[Editors’ note]*** *See text in section 4.2 about three cases: 1) re-use an existing TE tunnel, 2) modify an existing TE tunnel (with or without the need to setup new underlay optical tunnels) and 3) setup a new TE tunnel (with or without the need to setup new underlay optical tunnels)*

### Multi-domain and multi-layer path computation

When a new TE tunnel 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 model/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 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 abstact 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.  
     
   With this approach the role of P-PNC is minimized, i.e. is limited to management.
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 single domains. Therefore, when setting up the service, they must consider the connection requirements such as bandwidth, amplification, wavelength continuity, and non-linear impairments that may affect the 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.

### Hard Isolation

For example, when “Hard Isolation with, or without, deterministic latency” TE binding requirement is applied for a L2/L3 VPN network service, new Optical Tunnels need to be setup to support new IP links between PEs and BRs dedicated only to carry the traffic for the given L2/L3 VPN.

The MDSC needs to identify the set of packet domains to traverse and their BRs. This requires the MDSC to request each O‑PNC to compute the intra‑domain optical paths between each PEs/BRs pairs.

When requesting optical path computation to the O-PNC, the MDSC needs to take into account the inter-layer peering points, such as the interconnections between the PE/BR nodes and the edge Optical nodes (e.g., using the inter-layer lock or the transitional link information, defined in [RFC8795]).

When the optimal multi-layer/multi-domain path has been computed, the MDSC requests each O-PNC to setup the selected Optical Tunnels and P‑PNC to setup the intra‑domain MPLS‑TE Tunnels, over the selected Optical Tunnels. MDSC also request P-PNCs to properly configures their BGP speakers and the PE/BR forwarding tables to ensure that the L2/L3 VPN traffic is properly forwarded.

### Shared Tunnel Selection

In case of shared tunnel selection, the MDSC needs to check if there is a multi-domain path which can support the L2/L3VPN end-to-end TE service requirements (e.g., bandwidth, latency, etc.) using existing intra-domain MPLS-TE tunnels.

If such a path is found, the MDSC selects the optimal path from the candidate pool and request each P‑PNC to setup the L2/L3VPN service using the selected intra­‑domain MPLS‑TE tunnel, between PE/BR nodes.

Otherwise, the MDSC should detect if the multi‑domain path can be setup using existing intra‑domain MPLS-TE tunnels with modifications (e.g., increasing the tunnel bandwidth) or setting up new intra-domain MPLS‑TE tunnel(s).

The modification of an existing MPLS‑TE Tunnel and the setup of a new MPLS‑TE Tunnel may also require multi-layer coordination e.g., in case the available bandwidth of underlying Optical Tunnels is not sufficient. Based on multi-domain/multi-layer path computation, the MDSC can decide for example to modify the bandwidth of an existing Optical Tunnel (e.g., ODUflex bandwidth increase) or to setup new Optical Tunnels to be used as additional LAG members of an existing IP link or as new IP links to re-route the MPLS‑TE Tunnel.

## IP/MPLS Domain Controller and NE Functions

IP/MPLS networks are assumed to have multiple domains. Each domain, corresponding to either an IGP area or an Autonomous System (AS) within the same operator network, is controlled by an IP/MPLS domain controller (P‑PNC).

Among the functions of the P‑PNC, there are the setup or modification of the intra‑domain SR‑TE paths, between PEs and BRs, and the configuration of the VPN services, such as the VRF, in the PE nodes, as shown in Figure 2:

+------------------+ +------------------+

| | | |

| P‑PNC1 | | P‑PNC2 |

| | | |

+--|-----------|---+ +--|-----------|---+

| 1.Tunnel | 2.VPN | 1.Tunnel | 2.VPN

| Config | Provisioning | Config | Provisioning

V V V V

+---------------------+ +---------------------+

CE / PE tunnel 1 BR\ / BR tunnel 2 PE \ CE

o--/---o..................o--\-----/--o..................o---\--o

\ / \ /

\ Domain 1 / \ Domain 2 /

+---------------------+ +---------------------+

End-to-end tunnel

<------------------------------------------------->

1. IP/MPLS Domain Controller & NE Functions

It is assumed that BGP is running in the inter-domain IP/MPLS networks for L2/L3VPN. The P‑PNC controller is also responsible for configuring the BGP speakers within its control domain, if necessary.

The BGP would be responsible for the end-to-end tunnel label distribution on PE and BR nodes. The MDSC is responsible for selecting the BRs and the intra-domain MPLS‑TE Tunnels between PE/BR nodes.

If new MPLS‑TE Tunnels are needed or modifications (e.g., bandwidth increase) to existing MPLS\_TE Tunnels are needed, as outlined in section 2.2, the MDSC would request their setup or modifications to the P‑PNCs (step 1 in Figure 3). Then the MDSC would request the P‑PNC to configure the VPN, including selecting the intra‑domain TE Tunnel (step 2 in Figure 3).

The P‑PNC should configure, using mechanisms outside the scope of this document, the ingress PE forwarding table, e.g., the VRF, to forward the VPN traffic, received from the CE, with the following three labels:

* VPN label: assigned by the egress PE and distributed by BGP;
* end‑to‑end LSP label: assigned by the egress BR, selected by the MDSC, and distributed by BGP;
* MPLS-TE tunnel label, assigned by the next hop P node of the tunnel selected by the MDSC and distributed by mechanism internal to the IP/MPLS domain (e.g., RSVP-TE).

## Optical Domain Controller and NE Functions

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

The O‑PNC is responsible to:

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

# 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.

## 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.

## 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].

### 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:

* The Base Network Model, defined in the “ietf-network” YANG module of [RFC8345];
* The Base Network Topology Model, defined in the “ietf-network-topology” YANG module of [RFC8345], which augments the Base Network Model;
* 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 also use the Ethernet Topology Model, defined in the “ietf-eth-te-topology” YANG module of [CLIENT-TOPO], which augments the TE 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 use the following common notifications YANG data models at the MPI:

* Dynamic Subscription to YANG Events and Datastores over RESTCONF as defined in [RFC8650];
* Subscription to YANG Notifications for Datastores updates as defined in [RFC8641].

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

### 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:

* The WSON Topology Model, defined in the “ietf-wson-topology” YANG module of [WSON-TOPO];
* the Flexi‑grid Topology Model, defined in the “ietf-flexi-grid-topology” YANG module of [Flexi‑TOPO];
* the OTN Topology Model, as defined in the “ietf-otn-topology” YANG module of [OTN-TOPO].

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

* The WSON Tunnel Model, defined in the “ietf-wson-tunnel” YANG modules of [WSON-TUNNEL];
* the Flexi‑grid Tunnel Model, defined in the “ietf-flexi-grid-tunnel” YANG module of [Flexi‑TUNNEL];
* 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 .

### YANG data models at the Packet MPIs

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

* The L3 Topology Model, defined in the “ietf‑l3‑unicast‑topology” YANG module of [RFC8346], which augments the Base Network Topology Model;
* 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];
* 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:

* L3VPN Network Model defined in “ietf-l3vpn-ntw” module of draft-ietf-opsawg-l3sm-l3nm [L3NM];
* L2VPN Network Model defined in “ietf-l2vpn-ntw” module of draft-ietf-barguil-opsawg-l2sm-l2nm [L2NM].

The packet PNC uses also the L2NM and L3NM TE Service Mapping models, defined in “ietf-l2nm-te-service-mapping” and “ietf-l3nm-te-service-mapping” modules of [TSM], which agments the L2NM and L3NM Network Models.

## 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 list 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].
2. 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 RESTOCONF/YANG interface is added to an existing PCEP deployment (brownfield scenario).

Section 4 of this draft analyses the case where a single RESTCONF/YANG interface is deployed at the MPI (i.e., option 1 above).

# Multi-layer and multi-domain services scenarios

Multi-layer and multi-domain scenarios, based on reference network described in section 2, and very relevant for Service Providers, are described in the next sections.

For each scenario, existing IETF protocols and data models, identified in sections 3.1 and 3.2, are analysed with particular focus on the MPI in the ACTN architecture.

## Scenario 1: inventory, service and network topology discovery

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

* the network topology, at both optical and IP layers, in terms of nodes and links, including the access links, IP inter-domain links as well as cross-layer links;
* the optical tunnels supporting multi-layer intra-domain IP links;
* both intra-domain and inter-domain network services within the network;
* the SR-TE paths supporting those L2/L3 VPN network services;
* 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 IP-Optical multi-layer view.

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

Each PNC provides to the MDSC an abstracted or full topology view of the optical or of the IP topology of the domain it controls, as described in section xxx and yyy. This topology can be abstracted in the sense that some detailed NE information is hidden at the MPI. All or some of the NEs and related physical links are exposed as abstract nodes and logical (virtual) links, depending on the level of abstraction the user requires. This information is key to understanding both the inter-domain IP links (seen by each controller as UNI interfaces but as I-NNI interfaces by the MDSC) and the cross-layer mapping between IP and WDM layer.

*The paragraph above requires further discussion, in particular regarding the topology abstraction.*

*Should we move here (or in a new 4.1.x section) the information from section 3.2.2 about the type of optical topology (WSON, flexi-grid or OTN) being reported by O-PNCs?*

*Should we move here (or in a new 4.1.x section) the information from section 3.2.3 about SR-TE topology?*

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 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.

It should be possible at MDSC level 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, MPLS tunnel switched from primary to back-up path etc.). As specified in [RFC7923], MDSC must subscribe to specific objects from PNC YANG datastores for notifications.

### Optical topology discovery

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

*Provide details on the optical domain abstraction (yes as discussed in 2021-12-21)*

* *One TE node for each ROADM in the DWDM topology and one TE node for each OTN switching node in the OTN topology*
* *Optical transponders are reported as DWDM TTPs within the TE node regardless of whether they are integrated within the ROADM or external to the ROADM, but still under the control of the O-PNC (abstraction)*
* *One TE link for each OMS link, abstracting the OTS links and iLAs*
* *One TE link for each OTN link (single-layer or multi-layer)*

The Optical Transponders and, optionally, the OTN access cards, are reported by the O‑PNC as Trail Termination Points (TTPs), defined in [TE‑TOPO], within the Optical Topology. The association between the Ethernet cross-layer link and the Optical TTP is reported using the Inter Layer Lock (ILL) identifiers, defined in [TE‑TOPO], within the Ethernet Topology and Optical Topology, exposed by the O‑PNC.

The optical links are discovered by 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 topology, 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, reports in the hierarchical-link container which multi-layer single-domain OTN link each DWDM tunnel supports. The MDSC can use this information to discover the path within the DWDM network that supports a multi-layer OTN link.

LTPs terminating the on optical nodes (e.g., )

### Optical paths 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, regardless of the mechanism being used to set them up.

When the optional OTN layer is deployed within the optical domain, the OTN Tunnel Model is used to report the OTN tunnels and tunnel segments established within the optical network, regardless of the mechanism being used to set them up.

The Ethernet client signal Model is used to report all the connectivity provided by optical tunnels between Ethernet edge LTPs, terminating a cross-layer link, regardless of the mechanism being used to set them up.

In other words, the O-PNCs report in their operational datastores all the Ethernet client signals and all the optical tunnels setup by the MDSC at the MPI, using the mechanisms described in section 4.2.2, as well as those setup by other means, such as static configuration, which are outside the scope of this document.

### SR-TE 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].

The P-PNCs report the full SR-TE network topology providing all the information that is required by the MDSC to perform multi-domain SR-TE path computation. In particular, one TE node is reported for each IP router and one TE link is reported for each intra-domain IP link.

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

*Shall we report the underlay ETH link for single-layer intra-domain IP link or reporting the IP link is sufficient? Reporting the underlay ETH link could facilitate building the relationship with the inventory as well as expose whether an single-layer intra-domain IP link is supported by a LAG or not.*

### 

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

Figure 3

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 4.2.3, as well as the SR-TE paths being setup by other means, such as static configuration, which are outside the scope of this document.

### Inter-domain links discovery

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

* Inter-domain IP links between two adjancent IP domains;
* Cross-layer links between an an IP domain and an adjacent optical domain;
* Access links between a CE device and a PE router.

All the three types of links are Ethernet physical links.

It is worth noting that the P‑PNC may not be aware whether an external Ethernet physical link is a cross-layer link, an inter-domain 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 UNI Topology Model defined in [UNI-TOPO]). This has been identified as a gap.

TheIP and cross-layer links

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.

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

*Should we provide more details information about how these inter-domain links are discovered?*

### Multi-layer IP links discovery

In case of a multi-layer intra-domain IP link, the P‑PNC also reports the two edge Ethernet LTPs that supports the two IP LTPs terminating that multi-layer intra-domain IP link.

The MDSC can therefore discover which Ethernet cross-layer links support the multi-layer intra-domain IP links, as described in section 4.1.5.

The MDSC can discover using the Client Signal Model which Optical Tunnels support the multi-layer intra-domain IP links.

### L2/L3 VPN network services discovery

TBA

### Inventory discovery

The 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] has 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.

### 

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

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

Figure 3 provides an example of an hub&spoke L3VPN 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.

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| CE13 |\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

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| CE14 | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_) (\_\_\_\_\_\_\_\_\_\_\_\_\_| CE23 |

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Optical Domain 1 Optical Domain 2

H / S = Hub VRF / Spoke VRF

\_\_\_\_ = Inter-domain interconnections

..... = SR policy Path 1

\_ \_ \_ = SR policy Path 2

1. Multi-domain L3VPN example

***[Editors’ note:]*** *Update the SR policy paths to show the intra-domain PE13-P16-P14 and inter-domain PE13-BR11-BR12-P24-PE23 paths. No need to show the TI-LFA in this figure. Remove also the intra-domain TI-LFA.*

There are many options to implement multi‑domain L3VPN, 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 assumed that:

* each packet domain in Figure 3 is implementing SR-TE and the stitching between two domains is done using end-to-end/multi-domain SR-TE
* the bandwidth of each intra‑domain SR-TE path is managed by its respective P-PNC
* binding SID is used for the end-to-end SR-TE path stitching
* each packet domain in Figure 3 is using TI-LFA, with SRLG awareness, for local protection within each domain.

***[Editor’s note:]*** *Analyze how TI-LFA can take into account multi-layer SRLG disjointness, providing that SRLG information is provided by the O-PNCs to the P-PNC throught the MDSC.*

It is assumed that the MDSC adopts the partial summarization model, described in section 2.1.2, having full visibility of the packet layer TE topology and an abstract view of the underlay optical layer TE topology.

The MDSC needs to translate the L2VPN/L3VPN SLA requirements to TE requirements (e.g., bandwidth, TE metric bounds, SRLG disjointness, nodes/links/domains inclusion/exclusion) and find the SR-TE paths between PE13 (hub PE) and, respectively, PE23 and PE14 (spoke PEs) that meet these TE requirements.

For each SR-TE path required to support the L3VPN, it is possible that:

1. A SR-TE path that meets the TE requirements already exist in the network.
2. An existing SR-TE path could be modified (e.g., through bandwidth increase) to meet the TE requirements:
   1. The SR-TE path characteristics can be modified only in the packet layer.
   2. 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:
   1. The new SR-TE path reuses existing underlay optical tunnels;
   2. 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).

For example, considering the L3VPN in Figure 3, the MDSC discovers that:

* a PE13-P16-PE14 SR-TE path already exists but have not enough bandwidth to support the new L3VPN, as described in section 1.1;
* 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 4.1;
* 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 4.2.1. 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.

The MDSC would therefore request:

* the O-PNC1 to setup a new optical tunnel between the ROADMs connected to P16 and PE14, as described in section 4.2.2;
* 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 4.2.2;
* the P-PNC1 to update the bandwidth of the selected SR‑TE path between PE13 and PE14, as described in section 4.2.3.

Considering for example the L3VPN in Figure 3, the MDSC can also decide that a new multi‑domain SR‑TE path needs to be setup 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 4.2.1, 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:

* a new underlay optical tunnel between PE13 and BR11, supporting a new IP link, as described in section 4.2.2;
* 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 4.2.2.

After that, the MDSC requests P-PNC2 to setup an SR-TE path between BR21 and PE23, with an explicit path (BR21, P24, PE23) as described in section 4.2.3. 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 assigned binding SID.

***[Editor’s Note]*** *Further investigation is needed for the SR specific extensions to the TE tunnel model.*

MDSC request P-PNC1 to setup an SR-TE path between PE13 and BR11, with an explicit path (PE13, BR11), specifying the inter‑domain link toward BR21 and the binding SID to be used for the end‑to-end SR-TE path stitching, as described in section 4.2.3. The P‑PNC1, knowing also the node and the adjacency SIDs assigned within its domain and the EPE SID assigned by BR11 to the inter‑domain link toward BR21, 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 [L3NM] 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.*

### Optical Path Computation

As described in section 2.1.2, the optical path computation is usually performed by the Optical PNC.

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

As discussed in [PATH‑COMPUTE], there are two options to request an Optical 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.

The 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.

### Multi-layer IP link Setup and Update

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 Optical Transponders (OTs), in case of DWDM network, or the two OTN access cards, in case of OTN networks, associated with the two access links.

The MDSC also requires the O‑PNC to steer the Ethernet client traffic between the two access Ethernet links over the Optical Tunnel.

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] is used between the two routers, the P- PNC can automatically discover the IP link being set up by the MDSC. The IP LTPs terminating this IP link are supported by the ETH LTPs terminating the two access links.

Otherwise, the MDSC needs to require the P‑PNC to configure an IP link between the two routers: the MDSC also configures the two ETH LTPs which support the two IP LTPs terminating this IP link.

***[Editor’s Note]*** *Add text for IP link update and clarify that the IP link bandwidth increase can be done either by LAG or by ECMP. Both options are valid and widely deployed and more or less the same from POI perspective.*

### 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].

The MDSC can use the [TE-TUNNEL] model to request the P‑PNC to setup TE paths specifying the explicit path to force the P‑PNC to setup the actual path being computed by MDSC.

The [TE-TUNNEL] model supports requesting the setup of both end-to‑end as well as segment TE paths (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.

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.

# Security Considerations

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

# 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.

# IANA Considerations

This document requires no IANA actions.

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1. OSS/Orchestration Layer

As discussed in section 2.1.1, in this document, the MDSC interfaces with the OSS/Orchestration layer and, therefore, it performs the functions of the Network Orchestrator, as defined in [RFC 8309].

* 1. MDSC NBI

2

Figure 4 network data



* data , defined innetwork network
* and L3NM data s, defined in and [L3NM] and L3VPNnetwork
* data

1. Multi-layer and multi-domain resiliency
   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.

* 1. 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:

1. 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.
2. 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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