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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, identifying the YANG data models being defined by the IETF to support this deployment architecture as well as specific scenarios relevant for Service Providers.

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

Table of Contents

1.	Introduction.....	3
2.	Reference architecture and network scenario.....	4
2.1.	L2/L3VPN Service Request in North Bound of MDSC.....	8
2.2.	Service and Network Orchestration.....	10
2.2.1.	Hard Isolation.....	12
2.2.2.	Shared Tunnel Selection.....	12
2.3.	IP/MPLS Domain Controller and NE Functions.....	13
2.4.	Optical Domain Controller and NE Functions.....	15
3.	Interface protocols and YANG data models for the MPIs.....	15
3.1.	RESTCONF protocol at the MPIs.....	15
3.2.	YANG data models at the MPIs.....	15
3.2.1.	Common YANG data models at the MPIs.....	16
3.2.2.	YANG models at the Optical MPIs.....	16
3.2.3.	YANG data models at the Packet MPIs.....	18
3.3.	PCEP.....	18
4.	Multi-layer and multi-domain services scenarios.....	19
4.1.	Scenario 1: inventory, service and network topology discovery.....	20
4.1.1.	Inter-domain link discovery.....	21
4.1.2.	IP Link Setup Procedure.....	22
4.1.3.	Inventory discovery.....	22
4.2.	L2VPN/L3VPN establishment.....	23

5.	Security Considerations.....	24
6.	Operational Considerations.....	24

7. IANA Considerations.....	24
8. References.....	24
8.1. Normative References.....	24
8.2. Informative References.....	25
Appendix A. Multi-layer and multi-domain resiliency.....	28
A.1. Maintenance Window.....	28
A.2. Router port failure.....	28
Acknowledgments.....	29
Contributors.....	29
Authors' Addresses.....	30

[1. Introduction](#)

The full automation of the management and control of Service Providers transport networks (IP/MPLS, Optical and also Microwave) is key for achieving the new challenges coming now with 5G as well as with the increased demand in terms of business agility and mobility in a digital world. ACTN architecture, by abstracting the network complexity from Optical and IP/MPLS networks towards MDSC and then from MDSC towards OSS/BSS or Orchestration layer through the use of standard interfaces and data models, is 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 possibly 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 of each other. There are technical differences between the technologies (e.g., routers vs. optical switches) and the corresponding network engineering and planning methods (e.g., inter-domain peering optimization in IP vs. 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. Last but not least, state-of-the-art packet and optical networks use sophisticated but complex technologies, and for a network engineer it may not be trivial to be a full expert in both areas. As a result, packet and optical networks are often operated in technical and organizational silos.

This separation is inefficient for many reasons. Both capital expenditure (CAPEX) and operational expenditure (OPEX) could be

significantly reduced by better 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, key scenarios for Packet Optical Integration (POI) are described from the packet service layer perspective. The objective is to explain the benefit and the impact for both the packet and the optical layer, and to identify the required coordination between both layers. Precise definitions of scenarios can help with achieving a common understanding across different disciplines. The focus of the scenarios are IP/MPLS networks operated as client of optical DWDM networks. The scenarios are ordered by increasing level of integration and complexity. 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 to better assess the feasibility of integration between IP and Optical DWDM domain (and optionally OTN layer), in an end-to-end multi-vendor service provisioning perspective.

2. Reference architecture and network scenario

This document analyses a number of 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:

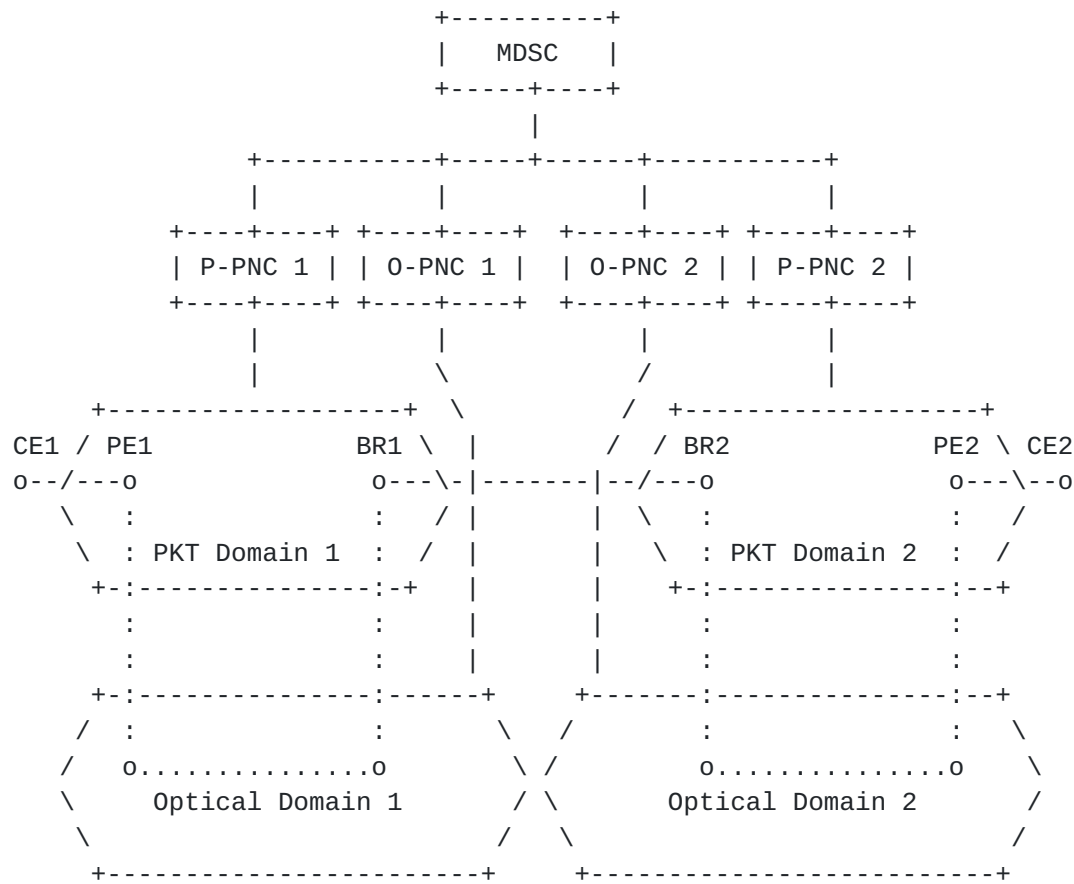


Figure 1 - Reference Scenario

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 IP domain, which can be either an Autonomous System (AS), [RFC1930], or an IGP area within the same operator network, and each Optical PNC (O-PNC) is responsible for controlling its Optical Domain.

The routers between IP 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 MPLS-TE network).

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

- o The domain boundaries between the IP and Optical domains are congruent. In other words, one Optical domain supports connectivity between Routers in one and only one Packet Domain;
- o Inter-domain links exist only between Packet domains (i.e., between BR routers) 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;
- o The interfaces between the Routers and the Optical NEs are "Ethernet" physical interfaces;
- o The interfaces between the Border Routers (BRs) are "Ethernet" physical interfaces.

This version of the document assumes that the IP Link supported by the Optical network are always intra-AS (PE-BR, intra-domain BR-BR, PE-P, BR-P, or P-P) and that the BRs are co-located and connected by an IP Link supported by an Ethernet physical link.

The possibility to setup inter-AS/inter-area IP Links (e.g., inter-domain BR-BR or PE-PE), supported by Optical network, is for further study.

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 a ROADM.

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 L2/L3VPN services.

Although the new technologies (e.g. QSFP-DD ZR 400G) are making convenient to fit the DWDM pluggable interfaces on the Routers, the deployment of those pluggable is not yet widely adopted by the operators. The reason is that most of operators are not yet ready to manage Packet and Transport networks in a unified single domain. As a consequence, this draft is not addressing the unified scenario. This matter will be described in a different draft.

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 the adaptation to the relevant network models. Such case is represented in Figure 2 of [\[RFC8453\]](#)
2. An implementation can choose to split the service-related and the network-related functions in 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 H-MDSC responsible for packet-optical multi-layer coordination, interfacing with one Optical L-MDSC, providing multi-domain coordination between the O-PNCs and one Packet L-MDSC, 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.

Please note that in 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. In this case, the MDSC is dealing with the network services requests received from the OSS/Orchestration layer.

[Editors'note:] Check for a better term to define the network services. It may be worthwhile defining what are the customer and network services.

The OSS/Orchestration layer is a key 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.

The functionality of the OSS/Orchestration layer as well as the interface toward the MDSC are usually operator-specific and outside the scope of this draft. This document assumes that the OSS/Orchestrator requests MDSC to setup L2VPN/L3VPN services through mechanisms which are outside the scope of the draft.

There are two main cases when MDSC coordination of underlying PNCs in POI context is initiated:

- o Initiated by a request from the OSS/Orchestration layer to setup L2VPN/L3VPN services that requires multi-layer/multi-domain coordination.
- o Initiated by the MDSC itself to perform multi-layer/multi-domain optimizations and/or maintenance works, beyond discovery (e.g. rerouting LSPs with their associated services when putting a resource, like a fibre, in maintenance mode during a maintenance window). Different to service fulfillment, the workflows then are not related at all to a service provisioning request being received from the OSS/Orchestration layer.

Above two MDSC workflow cases are in the scope of this draft. The workflow initiation is transparent at the MPI.

2.1. L2/L3VPN Service Request in North Bound of MDSC

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

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

Figure 2 shows an example of a possible control flow between the OSS/Orchestration layer and the MDSC to instantiate L2/L3VPN services, using the YANG models under definition in [\[VN\]](#), [\[L2NM\]](#), [\[L3NM\]](#) and [\[TSM\]](#).

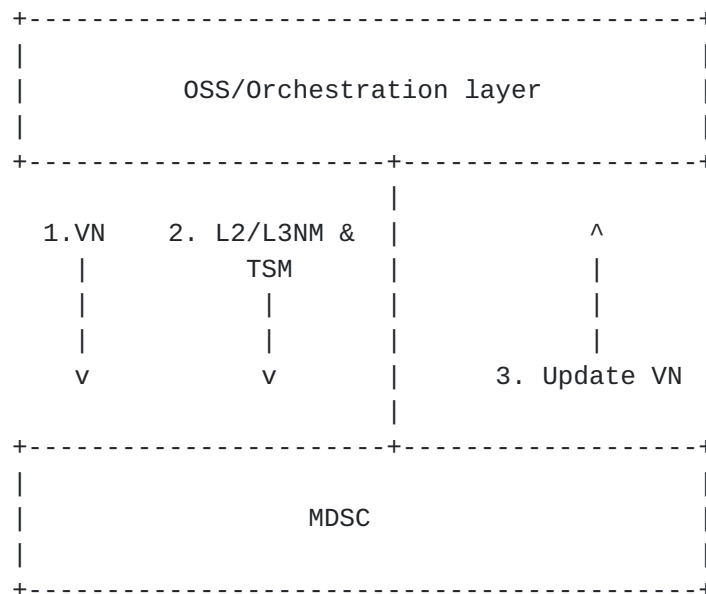


Figure 2 Service Request Process

- o The VN YANG model [[VN](#)], whose primary focus is the CMI, can also be used to provide VN Service configuration from a orchestrated connectivity service point of view, when the L2/L3VPN service has TE requirements. This model is not used to setup L2/L3VPN 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 between the connectivity matrix with the VN member from which 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 YANG model [[L2NM](#)], whose primary focus is the MPI, can also be used to provide L2VPN service configuration and site information, from a orchestrated connectivity service point of view.
- o The L3NM YANG model [[L3NM](#)], whose primary focus is the MPI, can also be used to provide all L3VPN service configuration and site information, from a orchestrated connectivity service point of view.

- o The TE & Service Mapping YANG model [[TSM](#)] provides TE-service mapping as well as site mapping.

- o TE-service mapping provides the mapping between a L2/L3VPN instance and the corresponding VN instances.
- o The TE-service mapping also provides the service mapping requirement type as to how each L2/L3VPN/VN instance is created with respect to the underlay TE tunnels (e.g., whether they require a new and isolated set of TE underlay tunnels or not). See [Section 2.2](#) for detailed discussion on the mapping requirement types.
- o Site mapping provides the site reference information across L2/L3VPN Site ID, VN Access Point ID, and the LTP of the access link.

[2.2. Service and Network Orchestration](#)

From a functional standpoint, MDSC represented in Figure 2 interfaces with the OSS/Orchestration layer and decouples L2/L3VPN service configuration functions from network configuration functions. Therefore in this document the MDSC performs the functions of the Network Orchestrator, as defined in [[RFC 8309](#)].

One of the important MDSC functions is to identify which TE Tunnels should carry the L2/L3VPN traffic (e.g., from TE & Service Mapping configuration) and to relay this information to the P-PNCs, to ensure the PEs' forwarding tables (e.g., VRF) are properly populated, according to the TE binding requirement for the L2/L3VPN.

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 which 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.

For the first three types, there could be additional TE binding requirements 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.

In order to fulfill the the L2/L3VPN end-to-end TE requirements, including the TE binding requirements, the MDSC needs to perform multi-layer/multi-domain path computation to select the BRs, the intra-domain MPLS-TE Tunnels and the intra-domain Optical Tunnels.

Depending on the knowledge that MDSC has of the topology and configuration of the underlying network domains, three models for performing path computation are possible:

1. Summarization: MDSC has an abstracted TE topology view of all of the underlying domains, both packet and optical. MDSC does not have enough TE topology information to perform multi-layer/multi-domain path computation. Therefore MDSC delegates the P-PNCs and O-PNCs to perform a 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 model presents an issue to P-PNC, which does not have the capability of performing a single-domain/multi-layer path computation (that is, P-PNC does not have any possibility to retrieve the topology/configuration information from the Optical controller). A possible solution could be to include a CNC function in the P-PNC to request the MDSC multi-domain Optical path computation, as shown in Figure 10 of [\[RFC8453\]](#). Another possible solution could be to rely on the MDSC recursive hierarchy, as defined in [section 4.1 of \[RFC8453\]](#), where, for each domain, a "lower-level MDSC" (L-MDSC) provides the essential multi-layer correlation and the "higher-level MDSC" (H-MDSC) provides the multi-domain coordination.
2. Partial summarization: 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. 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 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. The role of P-PNC is minimized, i.e. is limited to management.

3. Full knowledge: 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 model 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).

The current version of this draft assumes that MDSC supports at least model #2 (Partial summarization).

[Note: check with operators for some references on real deployment]

[2.2.1.](#) Hard Isolation

For example, when "Hard Isolation with or w/o deterministic latency" TE binding requirement is applied for a L2/L3VPN, new Optical Tunnels need to be setup to support dedicated IP Links between PEs and BRs.

The MDSC needs to identify the set of IP/MPLS domains 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 link 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 properly configures its BGP speakers and PE/BR forwarding tables to ensure that the VPN traffic is properly forwarded.

[2.2.2.](#) Shared Tunnel Selection

In case of shared tunnel selection, the MDSC needs to check if there is 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 as well as 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.

In all the cases, the labels used by the end-to-end tunnel are distributed in the PE and BR nodes by BGP. The MDSC is responsible to configure the BGP speakers in each P-PNC, if needed.

2.3. IP/MPLS Domain Controller and NE Functions

IP/MPLS networks are assumed to have multiple domains, where 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 MPLS-TE Tunnels, between PEs and BRs, and the configuration of the VPN services, such as the VRF in the PE nodes, as shown in Figure 3:

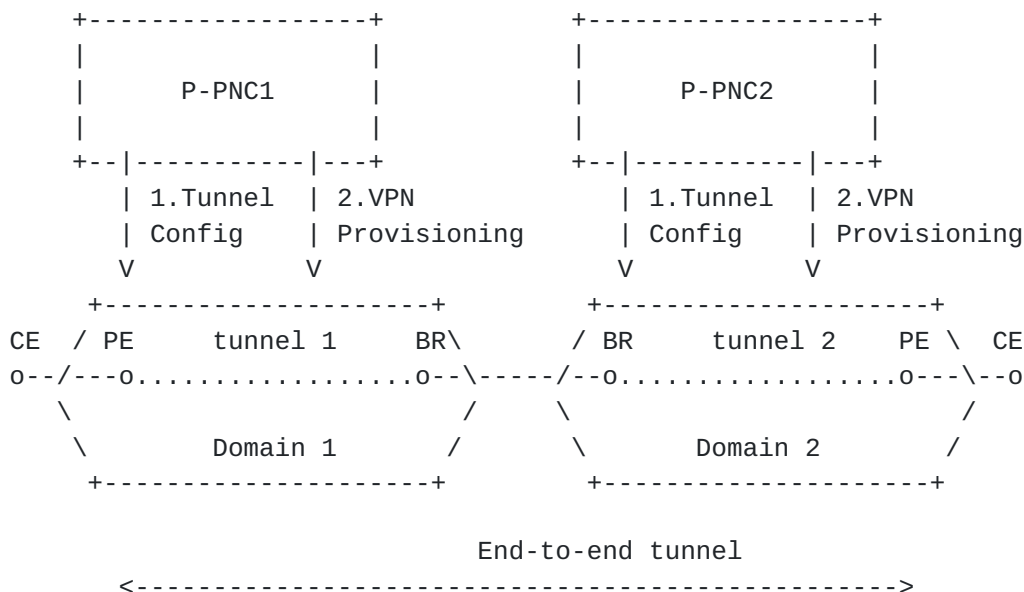


Figure 3 IP/MPLS Domain Controller & NE Functions

It is assumed that BGP is running in the inter-domain IP/MPLS networks for L2/L3VPN and that 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 label distribution of the end-to-end tunnel on PE and BR nodes. The MDSC is responsible for the selection of the BRs and of 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 the selection of 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:

- o VPN label: assigned by the egress PE and distributed by BGP;
- o end-to-end LSP label: assigned by the egress BR, selected by the MDSC, and distributed by BGP;

- o 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).

2.4. Optical Domain Controller and NE Functions

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:

- 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 which are applicable at all the MPI interfaces, between each PNC (Optical or Packet) and the MDSC, and also to all 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. 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 CMI 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 models at the MPI to report their abstract topologies:

- 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 with TE specific information.

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

Both Optical and Packet PNCs must use the following common notifications YANG models at the MPI so that any network changes can be reported almost in real-time to MDSC by the PNCs:

- 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 must be compliant with subscription requirements as stated in [[RFC7923](#)].

3.2.2. YANG models at the Optical MPIs

The Optical PNC also uses at least the following technology-specific topology YANG models, providing WDM and Ethernet technology-specific augmentations of the generic TE Topology Model:

- o The WSON Topology Model, defined in the "ietf-wson-topology" YANG modules of [[WSON-TOPO](#)], or the Flexi-grid Topology Model, defined in the "ietf-flexi-grid-topology" YANG module of [[Flexi-TOPO](#)].
- o Optionally, when the OTN layer is used, the OTN Topology Model, as defined in the "ietf-otn-topology" YANG module of [[OTN-TOPO](#)].

- o The Ethernet Topology Model, defined in the "ietf-eth-te-topology" YANG module of [[CLIENT-TOPO](#)].
- o Optionally, when the OTN layer is used, the network data model for L1 OTN services (e.g. an Ethernet transparent service) as defined in "ietf-trans-client-service" YANG module of [draft-ietf-ccamp-client-signal-yang](#) [[CLIENT-SIGNAL](#)].
- o The WSON Topology Model or, alternatively, the Flexi-grid Topology model is used to report the DWDM network topology (e.g., ROADMs and links) depending on whether the DWDM optical network is based on fixed grid or flexible-grid.

The Ethernet Topology is used to report the access links between the IP routers and the edge ROADMs.

The optical PNC uses at least the following YANG models:

- o The TE Tunnel Model, defined in the "ietf-te" YANG module of [[TE-TUNNEL](#)]
- o The WSON Tunnel Model, defined in the "ietf-wson-tunnel" YANG modules of [[WSON-TUNNEL](#)], or the Flexi-grid Media Channel Model, defined in the "ietf-flexi-grid-media-channel" YANG module of [[Flexi-MC](#)]
- o Optionally, when the OTN layer is used, the OTN Tunnel Model, defined in the "ietf-otn-tunnel" YANG module of [[OTN-TUNNEL](#)].
- o The Ethernet Client Signal Model, defined in the "ietf-eth-trans-service" YANG module of [[CLIENT-SIGNAL](#)].

The TE Tunnel model is generic and augmented by technology-specific models such as the WSON Tunnel Model and the Flexi-grid Media Channel Model.

The WSON Tunnel Model or, alternatively, the Flexi-grid Media Channel Model are used to setup connectivity within the DWDM network depending on whether the DWDM optical network is based on fixed grid or flexible-grid.

The Ethernet Client Signal Model is used to configure the steering of the Ethernet client traffic between Ethernet access links and TE Tunnels, which in this case could be either WSON Tunnels or Flexi-Grid Media Channels. This model is generic and applies to any technology-specific TE Tunnel: technology-specific attributes are provided by the technology-specific models which augment the generic TE-Tunnel Model.

3.2.3. YANG data models at the Packet MPIs

The Packet PNC also uses at least the following technology-specific topology YANG models, providing IP and Ethernet technology-specific augmentations of the generic Topology Models described in [section 3.2.1](#):

- o The L3 Topology Model, defined in the "ietf-l3-unicast-topology" YANG modules 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" in [draft-ietf-teas-l3-te-topo](#) [\[L3-TE-TOPO\]](#)
- o The Ethernet Topology Model, defined in the "ietf-eth-te-topology" YANG module of [\[CLIENT-TOPO\]](#), which augments the TE Topology Model

The Ethernet Topology Model is used to report the access links between the IP routers and the edge ROADMs as well as the inter-domain links between ASBRs, while the L3 Topology Model is used to report the IP network topology (e.g., IP routers and links).

- o The User Network Interface (UNI) Topology Model, being defined in the "ietf-uni-topology" module of the [draft-ogondio-opsawg-uni-topology](#) [\[UNI-TOPO\]](#) which augment "ietf-network" module defined in [\[RFC8345\]](#) adding service attachment points to the nodes to which L2VPN/L3VPN IP/MPLS services can be attached.
- o L3VPN network data model defined in "ietf-l3vpn-ntw" module of [draft-ietf-opsawg-l3sm-l3nm](#) [\[L3NM\]](#) used for non-ACTN MPI for L3VPN service provisioning
- o L2VPN network data model defined in "ietf-l2vpn-ntw" module of [draft-ietf-barguil-opsawg-l2sm-l2nm](#) [\[L2NM\]](#) used for non-ACTN MPI for L2VPN service provisioning

[Editor's note:] Add YANG models used for tunnel and service configuration.

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 is applicable 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](#)],

Peruzzini et al.

Expires November 14, 2021

[Page 18]

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 as well as 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. Further, the [section 6.1 of \[RFC8751\]](#) states the H-PCE applicability for inter-layer or POI.

[RFC8637] lists various PCEP extensions that are applicable 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 models described in the rest of this document. Depending on whether ACTN is deployed in a greenfield or browfield, two options are possible:

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

This approach is very attractive 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 but it uses PCEP for hierararchical 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).

[4. 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 are identified with particular focus on the MPI in the ACTN architecture. Non ACTN IETF data models required

for L2/L3VPN service provisioning between MDSC and IP PNCs are also identified.

4.1. Scenario 1: inventory, service and network topology discovery

In this scenario, the MDSC needs to discover through the underlying PNCs, the network topology, at both WDM and IP layers, in terms of nodes and links, including inter AS domain links as well as cross-layer links but also in terms of tunnels (MPLS or SR paths in IP layer and OCh and optionally ODUK tunnels in optical layer).

In addition, the MDSC should discover the IP/MPLS transport services (L2VPN/L3VPN) deployed, both intra-domain and inter-domain wise.

The O-PNC and P-PNC could discover and report the inventory information of their equipment that is used by the different management layers. In the context of POI, the inventory information of IP and WDM equipment can complement the topology views and facilitate the IP-Optical multi-layer view.

MDSC could also discover also the whole inventory information of both IP and WDM equipment and be able to 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 WDM or the IP topology of the domain it controls. This topology can be abstracted in the sense that some detailed NE information is hidden at the MPI, and 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 understand both the inter-AS domain links (seen by each controller as UNI interfaces but as I-NNI interfaces by the MDSC) as well as the cross-layer mapping between IP and WDM layer.

The MDSC should also maintain up-to-date inventory, service and network topology databases of both IP and WDM layers (and optionally OTN layer) 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 WDM layers (e.g.: which port, lambda/OTSi, 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 be able to correlate automatically 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 ROADMs.

It should be possible at MDSC level to easily correlate WDM 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 main to backup path etc.). As specified in [\[RFC7923\]](#) MDSC must be able to subscribe to specific objects from PNC YANG datastores for notifications.

[4.1.1. Inter-domain link discovery](#)

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

- o Links between two IP domains (ASes)
- o Links between an IP router and a ROADM

Both types of links are Ethernet physical links.

The inter-domain link information is reported to the MDSC by the two adjacent PNCs, controlling the two ends of the inter-domain link. The MDSC needs to understand how to merge these inter-domain Ethernet links together.

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 MDSC can understand how to merge these inter-domain links together using the plug-id attribute defined in the TE Topology Model [\[RFC8795\]](#), as described in [section 4.3 of \[RFC8795\]](#).

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

Both types of inter-domain links are discovered using the plug-id attributes reported in the Ethernet Topologies exposed by the two adjacent PNCs. The MDSC can also discover an inter-domain IP link/adjacency between the two IP LTPs, reported in the IP Topologies exposed by the two adjacent P-PNCs, supported by the two ETH LTPs of an Ethernet Link discovered between these two P-PNCs.

The static configuration requires an administrative burden to configure network-wide unique identifiers: it is therefore more viable for inter-AS links. For the links between the IP routers and the Optical NEs, the automatic discovery solution based on LLDP snooping is preferable when LLDP snooping is supported by the Optical NEs.

As outlined in [TNBI], the encoding of the plug-id namespace as well as of the LLDP information within the plug-id value is implementation specific and needs to be consistent across all the PNCs.

4.1.2. IP Link Setup Procedure

The MDSC requires the O-PNC to setup a WDM Tunnel (either a WSON Tunnel or a Flexi grid Tunnel) within the DWDM network between the two Optical Transponders (OTs) associated with the two access links.

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

The MDSC also requires the O-PNC to steer the Ethernet client traffic between the two access Ethernet Links over the WDM Tunnel.

After the WDM 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.

4.1.3. 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] 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, which is outside of the scope of this draft.

4.2. L2VPN/L3VPN establishment

To be added

[Editor's Note] What mechanism would convey on the interface to the IP/MPLS domain controllers as well as on the SBI (between IP/MPLS domain controllers and IP/MPLS PE routers) the TE binding policy dynamically for the L3VPN? Typically, VRF is the function of the device that participate MP-BGP in MPLS VPN. With current MP-BGP implementation in MPLS VPN, the VRF's BGP next hop is the destination PE and the mapping to a tunnel (either an LDP or a BGP tunnel) toward the destination PE is done by automatically without any configuration. It is to be determined the impact on the PE VRF operation when the tunnel is an optical bypass tunnel which does not participate either LDP or BGP.

New text to answer the yellow part:

The MDSC Network-related function will then coordinate with the PNCs involved in the process to provide the provisioning information through ACTN MDSC to PNC (MPI) interface. The relevant data models used at the MPI may be in the form of L3NM, L2NM or others and are exchanged through MPI API calls. Through this process MDSC Network-related functions provide the configuration information to realize a VPN service to PNCs. For example, this process will inform PNCs on what PE routers compose a L3VPN, the topology requested, the VPN attributes, etc.

At the end of the process PNCs will deliver the actual configuration to the devices (either physical or virtual), through the ACTN Southbound Interface (SBI). In this case the configuration policies may be exchanged using a Netconf session delivering configuration commands associated to device-specific data models (e.g. BGP[], QOS [], etc.).

Having the topology information of the network domains under their control, PNCs will deliver all the information necessary to create, update, optimize or delete the tunnels connecting the PE nodes as requested by the VPN instantiation.

5. Security Considerations

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

6. Operational Considerations

Telemetry data, such as the collection of 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.

7. IANA Considerations

This document requires no IANA actions.

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Peruzzini et al.

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[Page 25]

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Appendix A. Multi-layer and multi-domain resiliency

A.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.

A.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 backup 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-optimisation 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

Peruzzini et al.

Expires November 14, 2021

[Page 29]

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: youngleetx@gmail.com

Jeff Tantsura
Apstra

Email: jefftant.ietf@gmail.com

Paolo Volpato
Huawei

Email: paolo.volpato@huawei.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