Requirements for Integrated Packet Optical SDN

OIF-INT-SDN-01.0

May 15, 2020

Implementation Agreement created and approved

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Working Group: **Networking WG**

TITLE: **Requirements for Integrated Packet Optical SDN**

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ABSTRACT: This document outlines requirements, reference architecture and use cases for integrated packet optical SDN, with the aim to provide an interoperable framework that can be deployed across service provider community. The applicability of existing standards is also analyzed.

1 Table of Contents

2 List of Figures

3 List of Tables

4 Document Revision History

Table 1 Document Revision History

Issue No.	Issue Date	Details of Change
oif2018.349.03	10/1/2018	Initial Draft
oif2018.349.04	10/31/2018	Updated based on editing session in 2018Q4 OIF Network WG Meetings and contributions input
oif2018.349.05	2/20/2019	1. Updates based on 1/29/2019 OIF Network and Operations WG conference calls and other contributions to address comments and add more details to the all relevant sections. 2. Updates from contributions, review comments from OIF 1Q2019 OIF Network WG Tucson meetings
oif2018.349.06	5/14/2019	Updated based on contributions in Q2 2019 and liaison feedback on ONF.
oif2018.349.07	10/23/2019	Updated based on contributions in Q4 2019.
oif2018.349.08	10/24/2019	Updated based on editing session in 2019Q4 OIF Network and Operations WG Meetings
oif2018.349.09	2/12/2020	Updated based on contributions in 2020Q1 OIF Network and Operations WG Meetings.
oif2018.349.10	03/15/2020	Finalize the text based on comments from 2nd straw ballot.

Working Group: Working Group Name

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5 Introduction

5.1 Problem Statement

Network Operators face challenges with their Packet and Optical access, aggregation and core transport networks. These networks often rely on an optical transport layer based on WDM switching using ROADMs. Packet networks stand out as the main client layer of this underlying WDM optical infrastructure. Current challenges and new requirements for these networks are listed below.

1. **Low efficiency in service provisioning**: Typically, legacy transport services are statically provisioned through an L1/L0 management plane. Manual intervention and elaborate workflows are needed to orchestrate cross-layer actions between multiple departments in the service provider networks. Service provisioning is complex, slow and error-prone.
2. **Ineffective network maintenance:** Management and troubleshooting of these networks is split across technology domains (Packet and Optical), requiring inter-department co-ordination and manual processes to map network failures, understand the impacts to network performance and as well as do detailed failure analysis.
3. **Inefficient network resources utilization**: Service providers need to deal with the explosive growth of traffic coming from packet services and content centric cloud applications. Other than just overprovisioning the network by increasing capacity and installing more forwarding capacity at each layer, new ways of optimizing the design are required to better accommodate traffic growth. Many times stranded capacity in existing networks is not visible and all links are not effectively used by layer specific routing algorithms without considering other paths available via other layers.
4. **New service requirements**: some of new last mile/access WDM networks, data center interconnect networks, and SD-WAN links require better SLAs, protection mechanisms and stricter KPIs. Meeting these requirements calls for sharing of performance measurements across layers, together with multi-layer path computation and routing algorithms.
5. **Open Standard API interfaces and programmatic access to network services**: use of standardized open APIs will help expose network capabilities and state information to applications for programmatic access to network services, simplifying operations, dynamic connection management and real time bandwidth modification to support data center interconnection services, new OTT Connection service models and cloud interconnections.

Enhanced control, planning and management mechanisms based on SDN packet/optical integration will enable better coordination between the transport network and its client layers (mainly IP), addressing the challenges as well as the new requirements stated above. In particular, Integrated Packet Optical SDN will support:

1. Multi-layer network visibility that allows operators to visualize and use stranded capacity in underlying networks otherwise wasted. This will improve network utilization.
2. Automated provisioning across layers to speed up the capacity delivery, reduce manual errors, lower overall operational cost and improve service delivery time, opening up new revenue streams and services differentiation for network operators

3. Better capacity management using on-demand connectivity and bandwidth modification
4. Better visibility into network capabilities for upper layer user applications as well as web-based users via open software interfaces (e.g. APIs) for better network resource utilization and monetization.
5. Integrated troubleshooting across layers including Packet and Optical allowing faster troubleshooting and problem resolution.
6. Multilayer resilience schemes that minimize Packet and Optical back-up resources, improving overall network resource utilization and reducing operator costs.

OIF [OIF Transport SDN Requirements] has specified OIF Carrier WG requirements on Transport Network features and functionalities to support deployment of Software Defined Networking (SDN) architectures, application, services and technologies.

A reference architecture for SDN in transport networks is given as shown in the figure below.

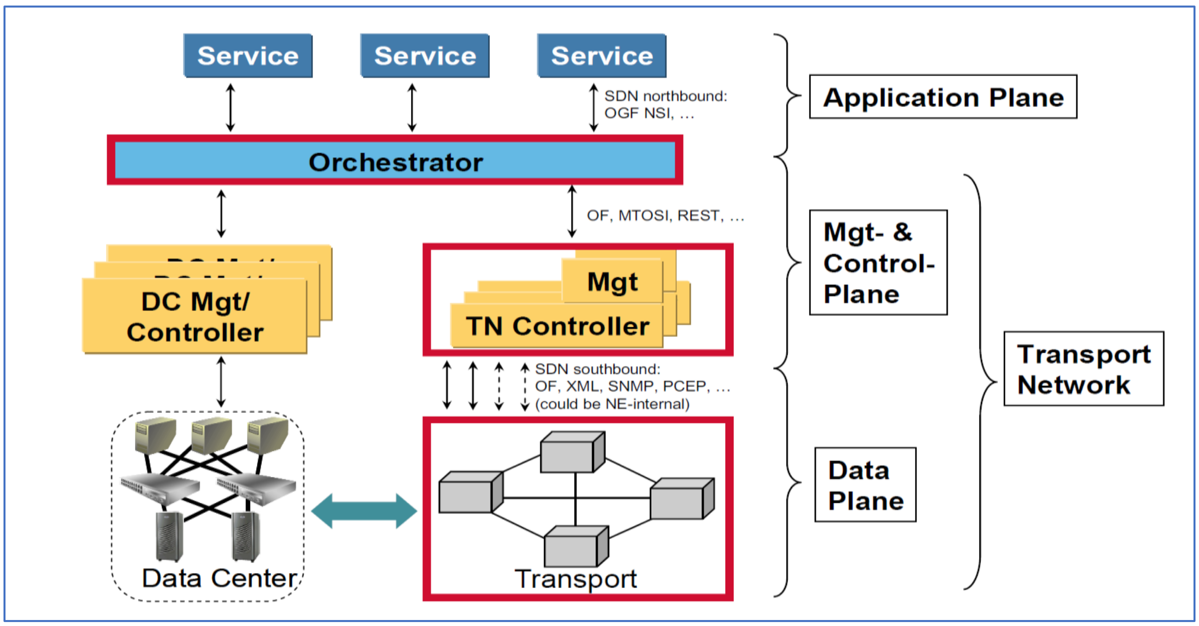

Figure 1 SDN reference architecture from OIF Carrier WG requirements on transport networks in SDN architectures

This Integrated Packet Optical SDN document follows the OIF reference SDN architecture, addressing the Control and Management plane and the transport network relevant part of the Orchestrator, and extends/builds on top of it, specifically focusing on the integration of Packet and Optical layer control and management for co-ordination between these layers to address the requirements outlined above.

Furthermore this document expands areas highlighted by red in Figure 1 and provides further details on integrated/unified service orchestration, management and control of Optical and Packet network domains.

5.2 Scope

This document will specify requirements, reference architecture and application scenarios for SDN based packet/optical integration with enhanced control, planning and management mechanisms.

Optical layer refers to the DWDM layer (L0) that essentially multiplexes multiple wavelengths onto a single fiber to carry combined optical signals across the physical link. OTN (L1) is included in optical layer as an electrical multiplexing layer to carry packet services on top of optical layers. Packet services primarily include layer 2 Ethernet services as well as layer 3 (IP and MPLS) services. Multi-layer or integrated refers to use of both optical and packet layer management and control information being combined into a unified and consistent view to generate better outcomes to the application layer.

This document will only address the control and management aspects of integrated packet and optical domains, not the data plane part.

Integrated Packet Optical SDN is a subset of SDN architecture functions comprising the optical and packet transport network-relevant SDN architecture functional blocks, the Control and Management plane and the transport network-relevant part of the Orchestrator.

Detailed technical specifications of how specific performance characteristics corresponding to a certain attribute or type in Integrated Packet Optical SDN may be implemented are outside the scope of this document.

5.3 Relationship to Other Standards Bodies

This document will put together applicable and available standard pieces from other standard bodies and organize them from a solution view. This document will analyze available standards to determine any gaps from solution point of view and develop or work with other standard bodies to address them.

Following is the list of SDOs and their corresponding areas/projects that are candidates for co-operation/reuse.

1) IETF –Abstraction and Control of TE Networks (ACTN), TE Topology and TE Tunnel YANG models and other transport technology models [10][11].
2) ONF - Transport API (TAPI) an application programming interface (API) for Transport networks, for service provisioning etc. [6].
3) MEF (Metro Ethernet Forum) – Driving MEF 3rd Network Vision by defining Lifecycle Service Orchestration (LSO) model specifically NRM, NRP, L1SM and L3SM projects [22].
4) ITU-T — ITU Telecommunications Sector - G.7701, G.7702, G.8080 [32][33][34].

Section 9 of this document specifically maps integrated packet optical SDN reference architecture, its functional blocks and interfaces to existing SDO work (where available) and analyze gaps, and propose solutions to address the gaps.

5.4 Document Organization

This document is organized as follows:

• Section 1: Contains the Table of Contents.

• Section 2: Contains the List of Figures.

• Section 3: Contains the List of Tables.

• Section 4: Provides Document Revision History and list of Input Contributions.

• Section 5: Introduction section that describes the background and motivation for Integrated Packet Optical SDN, defines the problem statement as well as need for the IA, defines the scope of the IA as well as introduces the structure of the whole document along with a list of contributors.

• Section 6: Provides use case scenarios for Integrated Packet Optical SDN and provides a set of specific requirements that arise in each of these use cases.

• Section 7: Provides overall general Architecture of Integrated Packet Optical SDN, then introduces each of the functional blocks in the architecture, and outlines interfaces between these functional blocks.

• Section 8: Provides a set of requirements including service, functional and interface requirements.

• Section 9: Maps Integrated Packet Optical SDN reference architecture, its functional blocks and interfaces to existing SDO work (where available), identifies gaps, and proposes solutions to address the gaps.

• Section 10: Summary.

• Section 11: Provides References.

• Appendix.

5.5 List of Contributors

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6 Use Cases

This Section provides use case scenarios for Integrated Packet Optical SDN (incl. applicability analysis). In this section, four typical use cases are given as well as related high-level requirements. Requirements for each use case are independent and may be duplicated. They will be further summarized in section 8 as functional requirements and interface requirements.

6.1 Use Case # 1: Cross-layer Network Awareness and Optimization

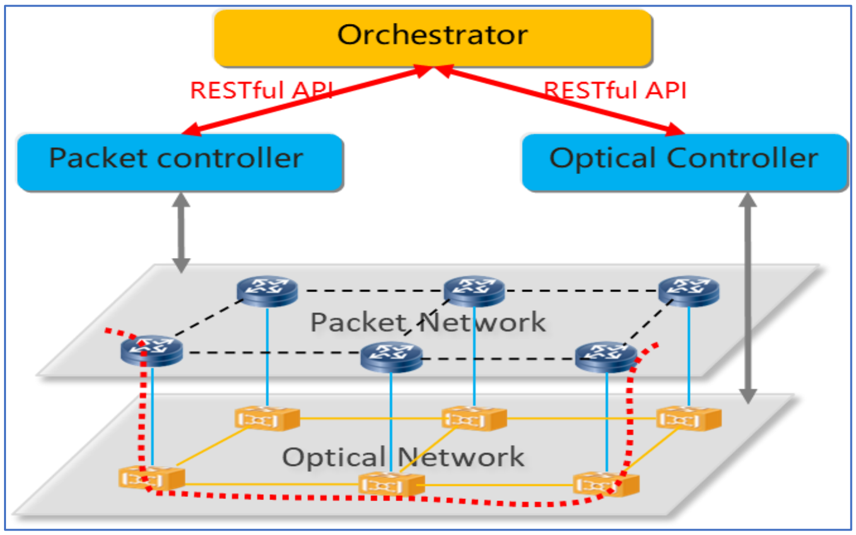

Figure 2 Cross-layer network awareness and optimization

1. Creation of a new packet service

In the first part of this scenario, multilayer integration of packet optical SDN is used to create new bandwidth in the Optical network in order to support a new service in the packet network. This new bandwidth connection originates from a source packet node and terminates in a destination packet node. At the intermediate points, depending availability of bandwidth and latency requirements, the connection may only pass through optical nodes as shown in figure above in red dotted lines.

Initially,

1) The Packet Controller retrieves the packet network topology, including nodes, ports and links, and exports this packet network topology to the Orchestrator. Note: A variety of options may apply to packet control, for example packet routing protocols such as BGP-LS may be used instead of RESTful API, also some packet layers such as IP may not have a central controller and the Orchestrator may participate in the IGP instead.

2) The Optical Controller retrieves the optical network topology, including the IP/packet ports adjacency in the optical domain, nodes, ports and links, and exports this optical network topology to the Orchestrator. Orchestrator combines these two topologies and generates an integrated topology map for its path computation services.

A new service request is received, in this case an RSVP-TE tunnel request for an MPLS tunnel. This can be received through the customer web portal or API interface, possibly through notification of a request received by a network element. Alternatively, the need for a new tunnel may be determined from analysis of IP traffic demands and network routing by the operator's network applications.

The Orchestrator determines from the request the endpoints and path requirements (including, for example, diversity constraints, QoS requirements, etc.) Based on this information and its combined topology knowledge of the Packet and Optical network, it computes a target path for the new service. The target end-to-end path may be the concatenation of several Optical and Packet paths in each domain based on availability of bandwidth, diversity constraints required for connection, or QoS requirements available in these path/network segments.

In most cases the optical network will be an underlay network to the packet network (with packet network as client layer and optical network as server layer).

The Orchestrator requests that the Packet Controller provisions the new TE tunnel in the packet network, after this is done, the Optical Controller provisions a new path into the Optical network.

A set of high-level requirements for new packet service are listed below.

R 1-01. Interface between domain Controllers (Packet and Optical Controllers) and Orchestrator should be authenticated and encrypted to ensure secure and tamperproof 2-way communication between Orchestrator and respective Controllers.

R 1-02. Orchestrator must support Packet and Optical domain co-ordination and multi-layer (Packet and Optical layer) path computation to setup network connections and manage operations in the respective domains.

R 1-03. Orchestrator must support integrated topology generation and updating based on the topology and network port adjacency maps and updates received from both Optical and Packet Controllers.

R 1-04. Orchestrator must support the ability to request path computation to both Optical and Packet Controllers for paths in each of their respective domains

R 1-05. Orchestrator must support alternative path computation if Optical or Packet Controller cannot find a successful path across its domain.

R 1-06. Both Optical and Packet Controllers must support on-demand network topology retrieval by the Orchestrator.

R 1-07. Packet and Optical Controllers must support an interface to the Orchestrator to provide topology updates and support topology queries.

R 1-08. Both Optical and Packet Controllers must support dynamic topology updates to Orchestrator based on any network changes such as node and link additions in their respective domains.

R 1-09. Both Optical and Packet Controllers must provide indications of network port, link and node failures to indicate dynamic status of networks in in their respective domains

R 1-10. Both Optical and Packet Controllers must support on-demand queries for network statistics and event driven updates (on bandwidth usage, bandwidth availability, latency, Packet Loss Ratio etc.) on the network links and nodes in specific domains.

R 1-11. Packet Controller must support discovery of IP/packet and optical network port adjacency and periodic validation of these packet/optical adjacencies.

R 1-12. Optical Controller must support discovery of IP/packet and optical network port adjacency and periodic validation of these packet/optical adjacencies

R 1-13. Orchestrator must support a secure web or API interface to its clients for new packet service including service creation, deletion and service status updates.

2. Bandwidth modification for an existing packet service

Operators currently handle dynamic bandwidth requirements by overprovisioning bandwidth, resulting in higher costs. With integrated packet optical SDN, it will be possible for the operator to provision bandwidth more efficiently, with the added capability for using SDN to dynamically adjust bandwidth based on demand.

In the second part of this scenario, multilayer integration of Packet Optical SDN is used to optimize the use of transport resources across both IP and Optical networks.

If congestion is encountered on an IP link, for example, based on LAG congestion, the Packet Controller notifies the Orchestrator. The Orchestrator then requests additional capacity from the Optical Controller on the given path.

The Optical Controller checks if the associated optical port capacity can be upgraded or a new path can be created using unused optical ports with higher capacity. If so, the Optical Controller provisions higher capacity on the path and notifies the Orchestrator.

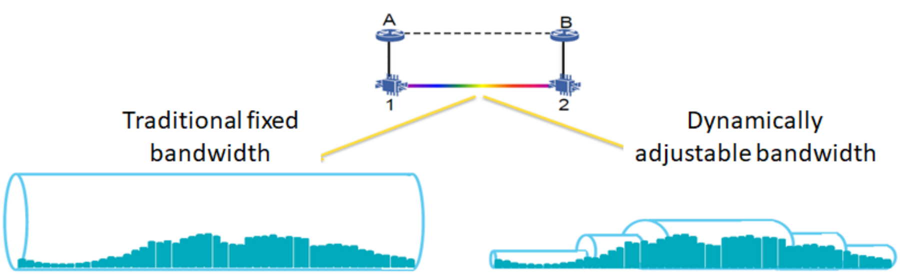

Figure 3 Dynamic bandwidth pipe adjustment

Compared with the traditional network mode, "Packet+Optical" multilayer network optimization allows the packet and optical networks to be used as a resource pool. Their resource allocation can change flexibly according to the business requirement, to improve the utilization of resources and reduce cost.

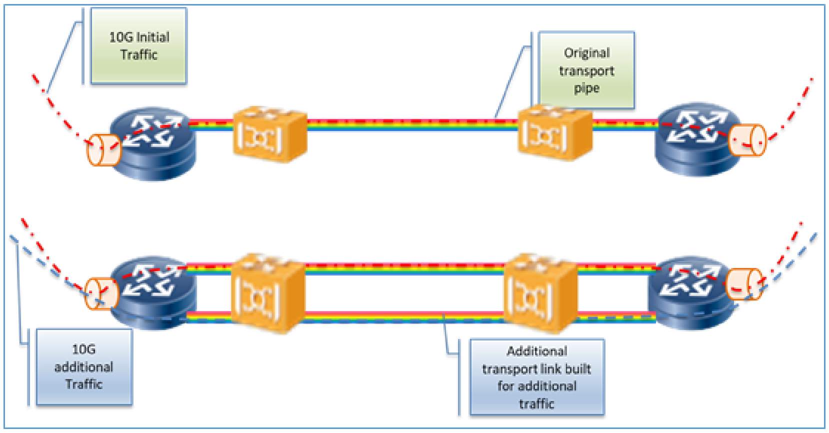

Figure 4 Bandwidth upgrade example by building additional transport links at optical layer

Figure 4 shows initially 10G packet bandwidth between two PE routers and a 10G transport link between these two routers in the optical layer. When bandwidth demand increases by another 10G, a 2nd transport link is built by the optical network and added to this connection. The Packet Controller updates both PE routers and binds the client port to this additional transport link to use this additional capacity. Similarly, when the capacity requirement drops back to 10G later on, the Orchestrator will inform the Optical and Packet Controllers to un-bind and remove the additional transport link. This upgrade of capacity could be driven by a time schedule which the Orchestrator implements based on customer input or online traffic analysis.

A set of high-level requirements for packet service bandwidth upgrade are listed below.

R 1-14. Packet Controller must support a set of configurable traffic parameters from the Orchestrator for packet/IP connections (e.g. a bandwidth profile including average and peak bandwidth, maximum end to end latency and maximum packet loss ratio, etc.).

R 1-15. Packet Controller must support a configurable specific measurement interval for monitoring traffic on the packet/IP connection as set by the Orchestrator

R 1-16. Packet Controller must monitor traffic flows on the existing connections and report any connections that cross the traffic thresholds to Orchestrator

R 1-17. Orchestrator must implement some level of hysteresis mechanism to avoid flapping of connections between high bandwidth and low bandwidth request scenarios.

R 1-18. Packet Controller must be able to swap server trails of an existing end to end packet connection without causing the packet loss ratio to exceed the pre-configured threshold.

R 1-19. Optical Controller must support in service setup of new connections and upgrade of existing connections based on the request from the Orchestrator.

6.2 Use Case #2: Fault Avoidance Using Cross Layer SRLG Information

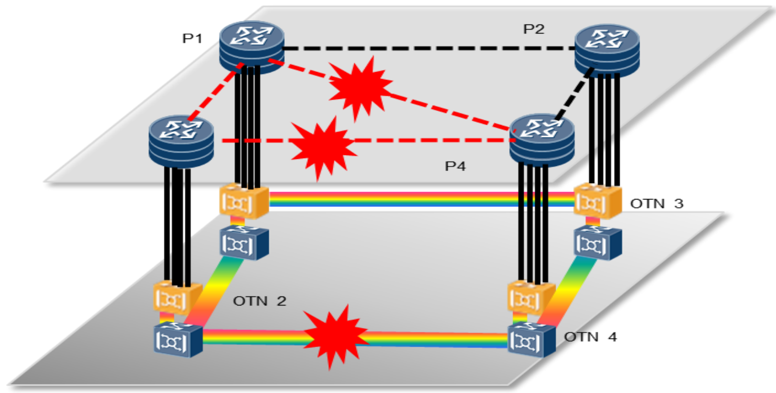

Figure 5 Cross-layer fault avoidance

Through Integrated Packet Optical SDN, the Orchestrator can capture and correlate the topology of Packet network and Optical network, simplifying the coordination of information and events. The fault of one fiber route may lead to the fault of multiple packet links. With multi-layer topology information, it is easy to identify the root cause of a fault. The network operator can identify the failed links in the topology more easily and identify the root cause of faults more quickly.

Moreover, multi-layer topology information can support the ability for the Orchestrator to do path separation, meaning that working path and protection path in packet layer will not be planned in the same SRLG. The Orchestrator obtains SRLG information from the Packet and Optical Controllers through SDN APIs, and the Packet Controller can avoid SRLG risks when calculating the working path and protection path, so as to improve the reliability of the packet network service.

Figure 6 provides an example:

There are two paths from P1 to P2, the purple one is the working path and the green one is the protection path. The optical layer path corresponding to the protection path will reroute if the optical path between NE1 and NE4 fails. If SRLG is not considered, working path and protection path in the packet layer may now pass through the same optical layer path. With Integrated Packet Optical SDN, SRLG information in the optical layer can be shared to the packet layer, and SRLG risk can be avoided when calculating packet paths. Considering SRLG sharing, P1 to P2 protection path can be changed to P1-P3-P4-P2, so that the corresponding optical layer paths will be disjoint.

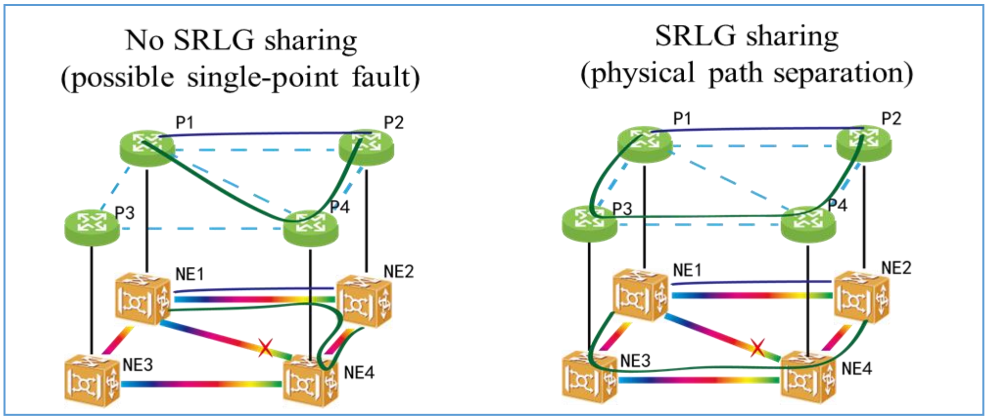

Figure 6 Cross-Layer path separation

A set of high-level requirements for cross-layer fault avoidance are listed below.

R 2-01. Orchestrator must be able to derive a detailed view of cross layer network topology by combining both packet and optical network topologies and interconnections between packet and optical networks.

R 2-02. Both Packet and Optical Controllers must provide an event notification subscription interface to the Orchestrator to receive service/connection related alarms and event notifications.

R 2-03. Orchestrator must be able to set filters and query scoped events from both Packet and Optical Controllers.

R 2-04. Orchestrator must provide options to the client to select or choose paths based on SRLG sharing avoiding single point of failure scenarios.

6.3 Use Case #3: Cross-layer Maintenance Coordination

In traditional network maintenance scenarios, optical network and packet network are usually maintained by different work teams. When cut-over maintenance is needed in the optical layer, cross-team communication and coordination may take days or even weeks to avoid network service interruption. In this use case it is assumed that the optical work team sets the operational status of optical links in the Optical Controller, and this information is passed to the Orchestrator using RESTful API. Using Integrated Packet Optical SDN, the orchestrator then uses this information to coordinate actions in the Packet Controller.

Integrated Packet Optical SDN allows the Optical Controller to notify the Orchestrator of the future availability of the optical link. Before cutting-over, the Optical Controller can set the operational state of the optical link to be “down” during the unavailable period of time and notify the Orchestrator of the scheduled change of optical link property. According to the availability information, the Orchestrator can reroute related packet services in advance to avoid being affected. When cut-over maintenance is finished, related packet services can be routed back to the original working path.

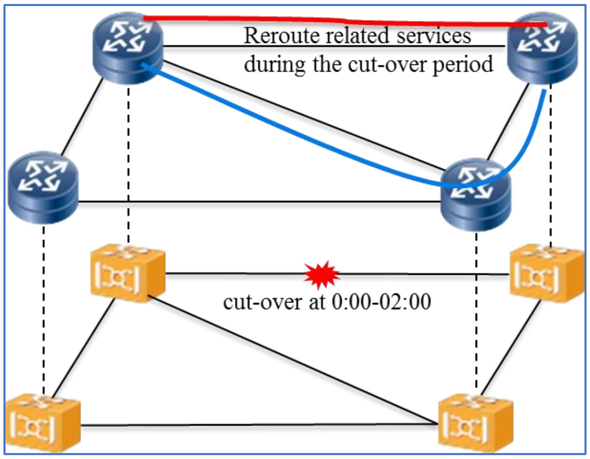

Figure 7 Cross-layer maintenance coordination

A set of high-level requirements for Cross-layer Maintenance Coordination are listed below.

R 3-01. Orchestrator must support scheduled changes of link and node state as indicated by the Optical and Packet Controllers using the SDN API;

R 3-02. Both Optical and Packet Controller must support a subscription interface allowing the Orchestrator to request topology updates;

R 3-03. The Orchestrator must support path computation with constraint conditions (include/exclude specific link or node);

R 3-04. Optical link and node properties passed from the Optical Controller to Orchestrator must include operational status;

R 3-05. Orchestrator must map/translate between packet services and optical nodes/links to support the coordination between Packet Controller and Optical Controller.

6.4 Use Case #4: Cross-layer Protection Coordination

In this use case, cross-layer protection coordination can be realized by port redundancy protection and optical protection/restoration. Compared with protection at the packet layer only, cross-layer protection coordination can improve the utilization of resources and reduce CAPEX. Port redundancy protection provides 1:N protection by using one redundant port for N working ports; whenever a working port breaks down, it can switch to the redundant one.

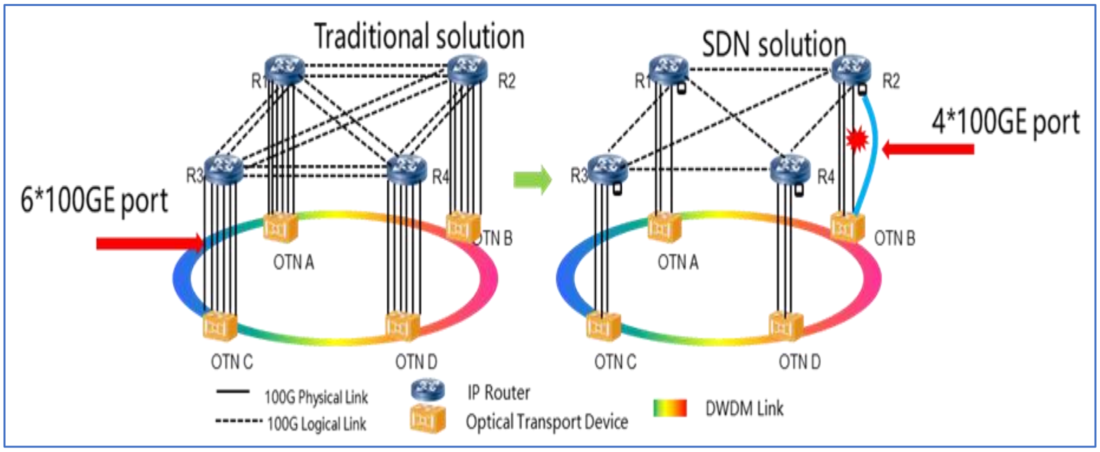

Figure 8 Cross-layer Protection Coordination

Figure 8 is an example to explain cross-layer protection coordination. In static full mesh IP network, if each IP link is provided with the ability to recover from either port failure or link failure, each IP router must use six 100GE ports to provide 1+1 protection in the IP layer. However, in an Integrated Packet Optical SDN solution, only four ports are needed for each IP router, three of which are needed to setup working links and the other extra port that is used for port redundancy. If any port among the three breaks down, port redundancy protection will be triggered and the broken port will be replaced by the redundant one. If the optical network has a failure, optical protection/restoration will be triggered.

Cross-layer protection coordination can also be realized using alarm suppression between different layers. Usually, protection mechanisms at different layers may be activated at different times depending on the configuration of the network. In the case of integrated packet optical SDN, the Controller could configure working and protection trails at both packet switching layer and optical layer. The Orchestrator can configure the timers at each layer so that protection actions are coordinated across layers. When a network connection failure happens, the server optical layer connection would detect the failure first, and the SSF (server signal fail) signal could be transferred to the client layer to help suppress the alarm at the client layer, in order to let the server layer finish the protection connection switching first. If the server layer cannot finish the protection switching in time, the client layer connections would start client layer protection switching accordingly. When the packet layer port fails, there is no SSF signal. The client layer protection could switch first.

A set of high level requirements for Cross-layer Protection Coordination are listed below.

R 4-01. Orchestrator must provide a detailed view of cross layer network topology by combining both packet and optical network topologies and interconnections between packet and optical networks.

R 4-02. Orchestrator must present a detailed and up to date view of the cross layer network topology with clear indications of faulty paths that correspond to current network failures and service degradations.

R 4-03. Both Optical and Packet Controller must support a subscription/un-subscription interface to allow the Orchestrator to subscribe to supported notifications and receive service/connection related alarms and event notifications.
R 4-04. Orchestrator must be able to set filters and query scoped events from both Packet and Optical Controllers.
R 4-05. Both Optical and Packet Controllers must provide indications on network port, link and node failures to indicate dynamic status of networks in their respective domains.
R 4-06. Packet Controller must support IP/packet and optical network port adjacency discovery and periodic validation of these packet/optical adjacency relationship.
R 4-07. Optical Controller must support IP/packet and optical network port adjacency discovery and periodic validation of these packet/optical adjacency relationship.
R 4-08. Orchestrator must support the configuration of hold-off timers.
R 4-09. Packet Controller must support configuration of 1:N ports protection within packet network.

7 Architecture

7.1 General architecture

Integrated Packet Optical SDN expands areas highlighted in red in Figure 1 and provides further details on the integrated/unified service orchestration, management and control of optical and packet domains.

A hierarchical Integrated Packet Optical SDN architecture is shown in the figure below and is based on a 3 tier model showing the interfaces and the information/control flow between the functional blocks.

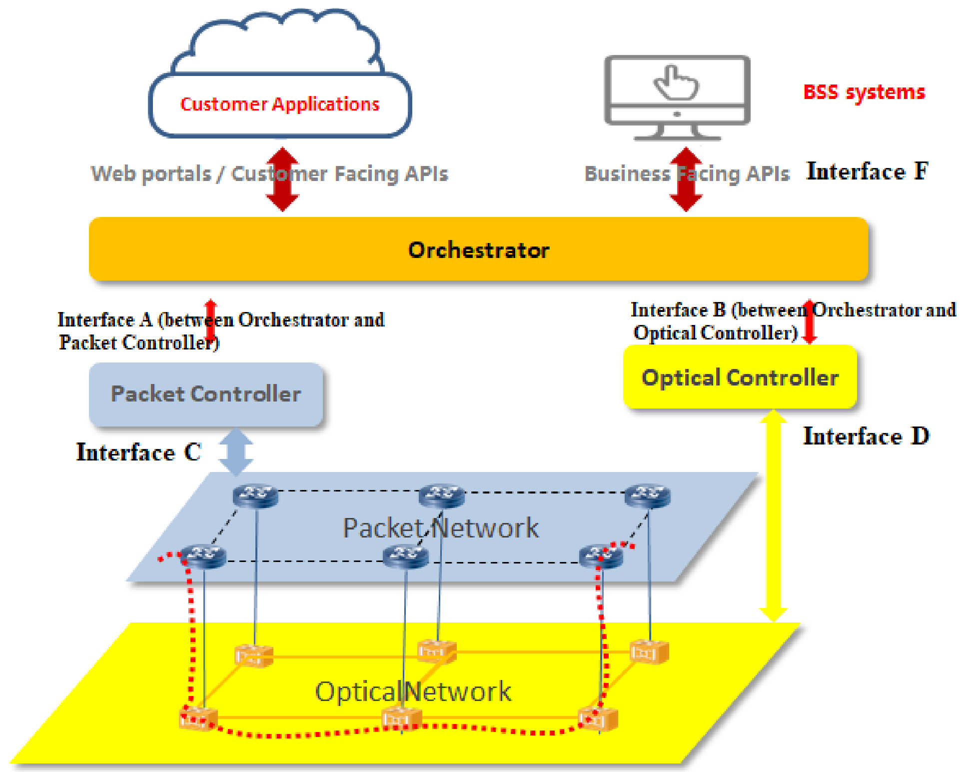

Figure 9 Hierarchical Architecture of Integrated Packet Optical SDN with interfaces

7.2 Introduction of each functional block in the architecture

This section describes the functional blocks in the architecture. It will also give examples on how to organize these functional blocks to support use cases. The service architecture description used in this section uses terminology defined in [20], it should be noted that service architecture is also defined in other standards specifications such as [4].

Main functional blocks of this architecture are as follows:

1. Orchestrator: This functional block provides customer request mapping/translation, service co-ordination, multi-domain coordination, network virtualization/abstraction. It interfaces with customer applications and interacts with specific domain Controllers to sequence domain path calculation/determination. This function oversees the specific aspects of different domains and builds a single end-to-end network topology in order to coordinate end-to-end path computation and path/service provisioning across multiple technology domains and provides a service centric view of underlying transport network to the upper layer applications. Typically, one Orchestrator manages connectivity within a single administrative domain or single service provider network.
2. **Optical Controller:** This functional block allows the Orchestrator to subscribe/ unsubscribe to service/connection related notifications/events. It oversees configuring the optical/OTN network elements, monitoring the topology of the optical network, and collecting information about the topology, network element configuration and management. Key functions are optical/OTN connection setup/deletion/modification, Optical/OTN network topology management and reporting, optical/OTN network performance measurement and reporting, KPI/SLA management

and as well as OAM related functions. In summary the Optical Controller fully manages the underlying optical/OTN network and provides an abstracted view of the underlying network to Orchestrator. The Optical Controller uses the Southbound Interface (SBI) to the optical network, which is out of scope of this document.

3. **Packet Controller:** This functional block allows the Orchestrator to subscribe/ unsubscribe to service/connection related notifications/events. It oversees configuring the packet network elements, monitoring the topology of the packet network, and collecting information about the topology, network element configuration and management. Key functions are packet layer end to end connection setup/deletion/modification, packet network topology management and reporting, packet network performance measurement and reporting, KPI/SLA management and as well as OAM related functions. In summary the Packet Controller fully manages the underlying packet network and provides an abstracted view of the underlying network to the Orchestrator. The Packet Controller uses the Southbound Interface (SBI) to the packet network, which is out of scope of this document.

7.3 Interface between these functional blocks

Several interfaces exist in the architecture as shown in Figure 9. These are as follows:

1. **Orchestrator to application layer interface (Interface F):** This is a business boundary between customer and network operator. It is used to request services for an application. All service-related information is conveyed over this interface (such as the service type, topology, bandwidth, and service constraints). Most of the information over this interface is agnostic of the technology used by network operators, but there are some cases (e.g., access link configuration) where it is necessary to specify technology-specific details.
2. **Interface between Orchestrator and Optical Controller (interface B):** This interface communicates requests for new connectivity or for bandwidth changes in the optical network. This interface presents an abstracted topology to the Orchestrator. The interface supports other common transport network functions and can be extended with optical network technology enhancements.
3. **Interface between Orchestrator and Packet Controller (interface A):** This interface communicates requests for new connectivity or for bandwidth changes in the packet network. This interface presents an abstracted topology to the Orchestrator. The interface supports other common packet network functions and can be extended with packet network technology enhancements.
4. **Interface between Optical Controller and Optical network (interface D):** This interface is out of scope of this document. Many different SBIs have been defined for different environments, technologies, standards organizations, and vendors. It is shown in Figure 9 for reference reasons only.
5. **Interface between Packet Controller and Packet network (interface C):** This is out of scope of this document. Many different SBIs have been defined for different environments, technologies, standards organizations, and vendors. It is shown in Figure 9 for reference reasons only.

8 Requirements

This section outlines the set of overall requirements for Integrated Packet Optical SDN.

8.1 Functional requirements

The goal of Integrated Packet Optical SDN is to provide the set of services, functions/operations that are needed to orchestrate, control and manage underlying multi-domain (Packet and Optical) networks to facilitate end to end connectivity/network services, network programmability, automation, efficient resource usage/sharing and network virtualization services to end users and operators.

Customers or users of these services could be either business customers requiring end to end connectivity services or operational or business departments of service providers of these networks.

Connectivity between these customer end points could be in any of multiple topologies (point to point, point to multi-point, mesh, hub-spoke) as desired by the customer.

This document uses the keywords "may", "must" and "should" to qualify optional, mandatory and recommended requirements respectively.

- **User management, security and authentication**
  - R-8-1-1: All the external and internal interfaces (interface between Orchestrator and users, interfaces between Orchestrator and Controllers, interfaces between Controllers and network elements and interface between peer Orchestrators) must support appropriate levels of security, authentication and encryption.
  1. General Security requirements outlined in section 4 of "**ONF TR-529" and "RFC 8453"** should be supported for all subsystems, functional blocks and interfaces in applicable areas.
  2. If NETCONF or RESTCONF network management protocols are used, then relevant IETF security standards should be followed.
- **Topology management**
  - R-8-1-2: Integrated Packet Optical SDN must support creation/retrieval of a global view of network topology
- **Path Computation services**
  - R-8-1-3: Integrated Packet Optical SDN must support End to End Path Computation services across layers
- **Service provisioning**
  - R-8-1-4: Integrated Packet Optical SDN must support E2E service provisioning, i.e., the ability to create, delete and modify end to end circuits/connections with specific SLA parameters.
- **Multi-layer coordination**
  - R-8-1-5: Integrated Packet Optical SDN must support Multi-layer coordination in L0/L1/L2/L3 Transport Networks for optimizing network resource utilization

- **Real-time integrated Network control**
  - R-8-1-6: Integrated Packet Optical SDN must support real-time integrated network control (e.g., fast recovery/reroute upon network failure or network changes)
- **Dynamic end to end Service Control**
  - R-8-1-7: Integrated Packet Optical SDN must support dynamic end to end Service Control, Policy enforcement and Traffic/SLA Monitoring
- **Notification services**
  - R-8-1-8: Integrated Packet Optical SDN must support dynamic and configurable Notification services

8.2 Interface requirements

This section describes interface characteristics of various interfaces that are required support the proposed architecture.

1. Interface from Orchestrator to application layer: A business boundary between customer and network operator. It is used to request network resources for an application. All service-related information is conveyed over this interface. Most of the information over this interface is agnostic of the technology used by network operators.

- R-8-2-1: Topology update notification: The Orchestrator should support notification to the application layer of topology changes.

2. Interface between Orchestrator to Packet Controller: used to collect topology of the packet network and control of the packet network domain. It communicates requests for new connectivity or for bandwidth changes in the packet network. In case of multi-domain environments, the Orchestrator needs to communicate with multiple Packet Controllers.

- R-8-2-2: Authentication： Orchestrator must support authentication of information from the Packet Controller.
- R-8-2-3: Topology Query： Orchestrator should support the ability to query the Packet Controller for topology details. Port adjacency information between packet network and optical network is in this scope.
- R-8-2-4: Topology Update Notification： Packet Controller must notify Orchestrator when topology changes.
- R-8-2-5: Path Computation: Orchestrator must support the ability to request path computation from the IP/Packet Controller, and the request message must support the transportation of path calculation policy and path constraint.
- R-8-2-6: Path configuration: Packet Controller must provide a packet network path configuration interface.

- R-8-2-7: Resource statistics query: Packet Controller must provide a packet network resource statistics query interface for network nodes, links and connections. Attributes such as bandwidth usage, bandwidth availability, latency, Packet Loss Ratio could be provided to the Orchestrator on-demand or driven by the event.

3. Interface between Orchestrator to Optical Controller: used to collect topology of the optical network and control of the optical network domain. It communicates requests for new connectivity or for bandwidth changes in the optical network. In case of multi-domain environments, the Orchestrator needs to communicate with multiple Optical Controllers.

- R-8-2-8: Authentication: Orchestrator must support authentication of information from the Optical Controller.
- R-8-2-9: Topology Query: Orchestrator should support the ability to query the Optical Controller for topology details. Port adjacency information between packet network and optical network is in this scope.
- R-8-2-10: Topology Update Notification: Optical Controller must notify Orchestrator when topology changes.
- R-8-2-11: Path Computation: Orchestrator must support the ability to request path computation from the Optical Controller, and the request message must support the transportation of path calculation policy and path constraint.
- R-8-2-12: Path Configuration: Optical Controller must provide an optical network path configuration interface.
- R-8-2-13: Resource Statistics Query: Optical Controller must provide an optical network resource statistics query interface for network nodes, links and connections. Attributes such as bandwidth usage, bandwidth availability, latency could be provided to the Orchestrator on-demand or driven by the event.

9 Mapping to existing standards/Gap analysis

This section will map integrated packet optical SDN reference architecture, its functional blocks and interfaces to existing SDO work (where available) and analyze gaps, propose solutions to address these gaps.

Architecture models from IETF, ONF and MEF that are pertinent to the proposed architecture presented in this document.

1. IETF Abstraction and Control of TE Networks (ACTN): ACTN architecture is a 3 layer hierarchical model as defined in [10]. The base architecture defines three hierarchical Controller types (CNC - Customer Network Controller, MDSC - Multi-Domain Service Coordinator, PNC - Provisioning Network Controller and the corresponding interfaces between these Controllers (CMI - CNC-MDSC Interface supporting customer service model and is used by customer Controller to communicate the service request or application demand, MPI - MDSC-PNC Interface supporting network configuration model, SBI (Southbound Interface) , the network device provisioning interface for creating forwarding state in the physical network requested via the PNC). The SBI is not in the scope of ACTN. ACTN detailed work at IETF has produced several YANG models covering these open interfaces between the Controllers as outlined in [15].

2. **ONF TAPI:** ONF Architecture: The Open Networking Foundation (ONF) defines an architecture where the SDN Controller exposes an Applications-Controller Plane Interface (A-CPI) to clients and uses a Data-Controller Plane Interface (D-CPI) to control server resources [4]. This relationship is recursive, so that a server SDN Controller exposes its A-CPI as the D-CPI for a client SDN Controller. A Common Information Model [31] is defined in ONF for these interfaces for which the Transport Controller realization is the Transport API, or TAPI. TAPI covers a basic set of control plane functions (Topology service, Connectivity service, Path computation service, Virtual network service and Notification and OAM services) plus technology-specific models for Photonic Media, OTN, Ethernet, DSR (Digital Signal Rate), and Equipment modeling. The ONF TAPI is applicable for an SDN controller to interface in a client-context to an application or another SDN controller, and also in a server-context to the network elements or another SDN controller. Depicted in Figure 10 below is one of the supported TAPI application scenarios. Detailed TAPI requirements can be found in [9] and [6]. ONF Transport API SDK is an open source project available on Github, *https://github.com/OpenNetworkingFoundation/TAPI*. The TAPI project delivers SDK releases periodically and includes TAPI UML information model, TAPI YANG schema, OpenAPI specification and Reference Implementation.

3. **MEF LSO projects:** MEF defines Lifecycle Service Orchestration (LSO) as an open and interoperable automation of management operations over the entire lifecycle of Layer 1, Layer 2 and Layer 3 Connectivity Services. This includes fulfillment, control, performance, assurance, usage, security, analytics and policy capabilities, over all the network domains that require coordinated management and control in order to deliver the services. In this LSO architecture, the LEGATO, PRESTO, ADAGIO and ALLEGRO interfaces are relevant from this document perspective. At the PRESTO interface reference point between service orchestration functionality (SOF) and Infrastructure Control and Management (ICM), MEF Network Resource Model (NRM) and MEF Network Resource Provisioning (NRP) models provide network connectivity services management and control aspects for the transport networks. MEF PRESTO interface specifications (MEF 59 and MEF 60) utilize the ONF TAPI with extensions for MEF services. In addition, MEF 63 and MEF 61 define layer 1 and Layer 3 service definitions between a Service Provider and Subscribers/customers. These interfaces can be considered as subset of the ALLEGRO interface that represents interaction between subscribers/customers and service providers in LSO domain. Details of MEF LSO, NRM, NRP L1SM and L3SM projects are available in [22], [23], [24], [25] and [26].

Figure 11 shows the architecture models of IETF, ONF and MEF that are pertinent to the proposed architecture presented in this document.

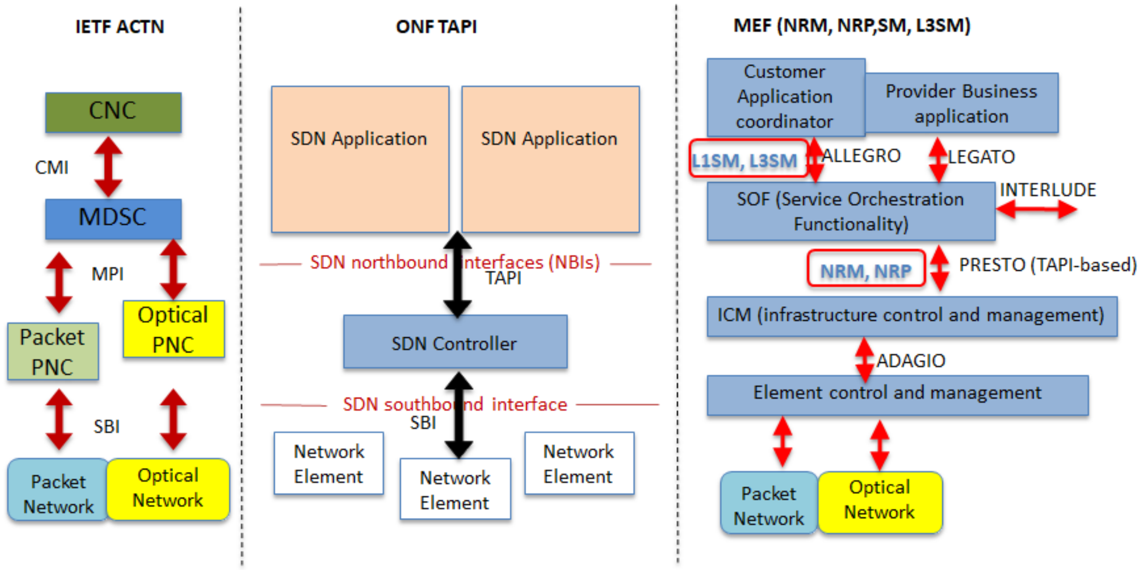

Figure 10 SDN Architecture Models of IETF ACTN, ONF TAPI and MEF LSO

The analysis of existing transport SDN standards will be based on the named reference interfaces of Integrated Packet Optical SDN as shown in Figure 11.

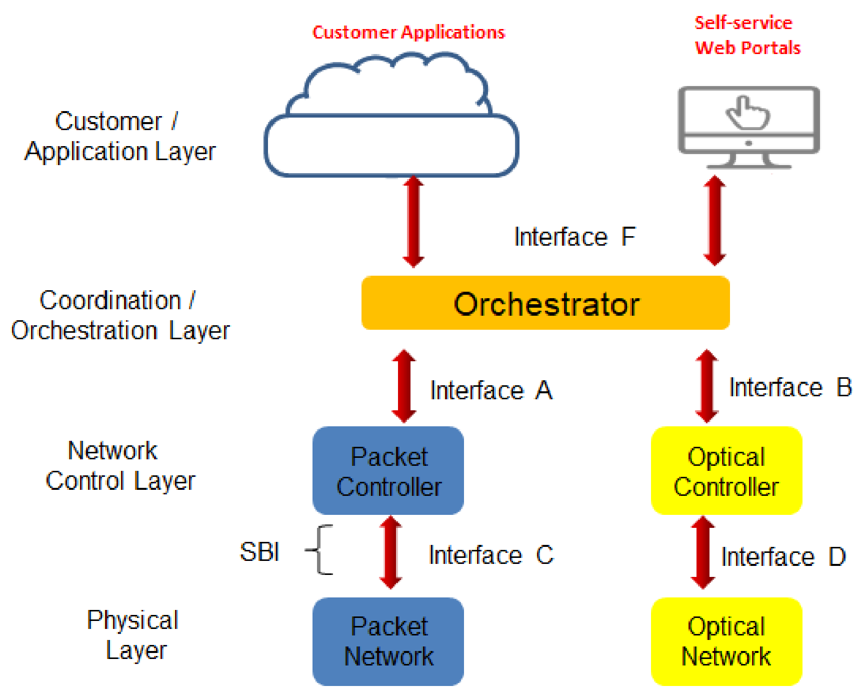

Figure 11 Reference Interfaces of Integrated Packet Optical SDN

Table 2 shows how the existing standards support the reference interfaces of the Integrated Packet Optical SDN.

Table 2 Mapping of relevant SDOs interface related work into Integrated Packet Optical SDN reference architecture

Integrated packet optical SDN reference Interfaces	IETF	ONF	MEF
Interface between Orchestrator and application layer Interface F	CMI (L2SM-RFC8466, L3SM-RFC8299)	NBI (possibly TAPI)	LEGATO ALLEGRO
Interface between Orchestrator and Packet Controller Interface A	MPI (e.g.: TE YANG model, TE Topo YANG model, L3 TE topo YANG)	A-CPI (TAPI)	PRESTO (Note 1)
Interface between Orchestrator and Optical Controller Interface B	MPI (e.g.: TE YANG model, TE Topo YANG model)	A-CPI (TAPI)	PRESTO (Note 1)
Interface between Packet Controller and packet network Interface C (out of scope)	SBI (PCEP, BGP-LS , NETCONF/YANG)	SBI (OpenFlow, TAPI)	ADAGIO (Could be PCEP, NETCONF/YANG)
Interface between Optical Controller and optical network Interface D (out of scope)	SBI (PCEP, NETCONF/YANG)	SBI (OpenFlow Optical, TAPI)	ADAGIO (Could be PCEP, NETCONF/YANG)

Note 1: MEF PRESTO utilizes ONF TAPI (see above).

Table 3 shows mapping of functions to different SDOs that are pertinent to the proposed architecture framework that is presented in this document.

Table 3 Mapping of relevant SDOs functions into Integrated Packet Optical SDN reference architecture

Integrated packet optical SDN reference functions	IETF	ONF	MEF
User management, security and authentication	√	√	√
Topology management	√	√	√
Path Computation services	√	√	-
Service provisioning	√	√	√
Multi-layer coordination	√	√	-
Real-time integrated Network control	√	√	-
Dynamic end to end Service Control	√	√	√
Notification services	√	√	-
Other functions (non-required)	Virtual Network management;	OAM Service, Virtual Network Service	

IETF ACTN (Abstract Abstraction and Control of TE Networks) is generated from the TE network perspective and naturally supports both packet and optical transport network technologies. The models for both packet and optical transport network technologies are rooted from the same base models (e.g. IETF TE YANG model (draft-ietf-teas-yang-te) and IETF TE Topo YANG model (draft-ietf-teas-yang-te-topo)). ACTN supports multi-domain coordination which is the main requirements of the integrated packet optical SDN as defined in this document. ACTN also supports telemetry that can help with the fault management, maintenance and protection purposes.

ONF TAPI supports the following functions: topology service, connectivity service, OAM service, path computation service, virtual network service, notification service (including subscription to telemetry-type measurements). Yang models for different transport technologies, i.e., ODU, OTSi and Ethernet are included in TAPI. TAPI supports Carrier Ethernet (L2), OTN (L1-ODU) and WDM (L0) transceiver and line system models, and supports multi-domain coordination. TAPI does not currently support IP or MPLS models, which limits the usage of TAPI to Ethernet control in an API between the Orchestrator and a Packet Network Controller. However, projects on extending TAPI to IP/MPLS have been initiated.

MEF LSO focuses on the network resource management and provisioning, which also meets the base requirements of integrated packet optical SDN. However, it is designed from the high level orchestration view and is more focused on the service model, e.g. L1 service model or Ethernet service model.

10 Summary

Four typical use cases of Integrated Packet Optical SDN are described in this IA. To support these use cases, functional requirements and interface requirements are further proposed as well as the architecture and related functional blocks. Finally, gap analysis compared with other existing SDOs are discussed. This IA aims at providing an interoperable framework that can break the management gap between packet network and optical network.

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12 Appendix A: List of companies belonging to OIF when document is approved

ADVA Optical Networking
Alibaba
Alphawave IP Inc.
Amphenol Corp.
AnalogX Inc.
Applied Optoelectronics, Inc.
Arista Networks
BitifEye Digital Test Solutions GmbH
BizLink Technology Inc.
Broadcom Inc.
Cadence Design Systems
China information and communication technology Group Corporation
China Telecom Global Limited
Ciena
Cisco Systems
Corning
Credo Semiconductor (HK) LTD
Dell, Inc.
EFFECT Photonics B.V.
Epson Electronics America, Inc.
eSilicon Corporation
Facebook
Foxconn Interconnect Technology, Ltd.
Fujikura
Fujitsu
Furukawa Electric Japan
Global Foundries
Google
Hewlett Packard Enterprise (HPE)
IBM Corporation
Idea Sistemas Electronicos S.A.
II-VI Incorporated
Infinera
InnoLight Technology Limited
Innovium
Inphi
Integrated Device Technology

Intel
IPG Photonics Corporation
Juniper Networks
Kandou Bus
KDDI Research, Inc.
Keysight Technologies, Inc.
Lumentum
MACOM Technology Solutions
Marvell Semiconductor, Inc.
Maxim Integrated Inc.
MaxLinear Inc.
MediaTek
Mellanox Technologies
Microchip Technology Incorporated
Microsoft Corporation
Mitsubishi Electric Corporation
Molex
Multilane SAL Offshore
NEC Corporation
NeoPhotonics
Nokia
NTT Corporation
O-Net Communications (HK) Limited
Open Silicon Inc.
Optomind Inc.
Orange
PETRA
Precise-ITC, Inc.
Rambus Inc.
Ranovus
Rianta Solutions, Inc.
Rockley Photonics
Rosenberger Hochfrequenztechnik GmbH & Co. KG
Samsung Electronics Co. Ltd.
Samtec Inc.
Semtech Canada Corporation
SiFotonics Technologies Co., Ltd.

Socionext Inc.
Spirent Communications
Sumitomo Electric Industries, Ltd.
Sumitomo Osaka Cement
Synopsys, Inc.
TE Connectivity
Tektronix
Telefonica SA
TELUS Communications, Inc.
UNH InterOperability Laboratory (UNH-IOL)
Verizon
Viavi Solutions Deutschland GmbH
Xelic
Xilinx
Yamaichi Electronics Ltd.
ZTE Corporation