TECHNICAL REPORT

TR-319 Part-B
Achieving Packet Network Optimization using DWDM Interfaces - Physically Separated Model

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Executive Summary

Network Operators face significant challenges in the operation of their access, aggregation and core networks. They need to cope with the steadily growing traffic from IP services and content-centric applications and they are facing pressure to bring new services to market more quickly than they have been able to in the past.

Networks worldwide are being transformed and optimized to cope with these challenges. Amongst the goals of this transformation are a reduction in the complexity of operations management and an improvement in the utilization of the network infrastructure.

Optical networking is a key enabler for high capacity, scalable aggregation, metro and long haul networks. Advances in optical technologies, e.g. the use of coherent optical technology, are allowing increases in the capacity and reach of the network. Technology advancements (at all levels of Data, Control and Management Plane) allow for better integration at the data plane and for better control and management integration.

TR-319 [1] addresses the use of optical transport and IP network standards and RFCs for IP and optical integration, to allow multi-vendor interoperability, and enables packet network optimization using DWDM Interfaces.

TR-319 Part-B specifies the Architecture and Requirements of the Physically Separated Model, the integration of packet and optical control and management planes of physically distinct packet and optical edge nodes for higher automation in a packet optical network.

1 Purpose and Scope

1.1 Purpose

Network Providers have identified the potential to better integrate their packet and DWDM/optical networks to address growing network capacity demands, increase efficiency and reduce OPEX. TR-319 Part-B specifically deals with packet and optical control plane integration.

Integrated packet/optical networks and network node equipment are based on a variety of protocols and functionalities specifications (e.g., physical layer, data plane, control plane, management plane, etc.) from different SDOs. TR-319 [1] documents identify the set of specifications that are necessary for implementation of integrated packet optical networks and networking equipment.
The objective of TR-319 [1] is to foster the development of interoperable solutions from multiple vendors to be the benefit of consumers and suppliers of broadband services alike.

A control plane allows easier operation of the network. The control plane specified in this document is based on GMPLS [18]. GMPLS-based network control and user-network interfaces may be used to ease the operation of interconnected packet and DWDM network domains.

1.2 Scope

TR-319 Part-B defines the Architecture and Nodal Requirements for the Physically Separated Model, enabled by the interaction of Control and Management Planes, including:

a. The Data plane as defined by IEEE specifications and ITU-T Recommendations.

b. The Control plane protocols and their applicability aspects, as defined by IETF RFCs and associated existing and evolving GMPLS extensions. Intra-optical network control plane aspects are not in scope.

c. The Management plane and operational aspects including the use of SDN.

2 References and Terminology

2.1 References

The following references are of relevance to this TECHNICAL REPORT. At the time of publication, the editions indicated were valid. All references are subject to revision; users of this TECHNICAL REPORT are therefore encouraged to investigate the possibility of applying the most recent edition of the references listed below.

A list of currently valid Broadband Forum Technical Reports is published at www.broadband-forum.org.

Document		Title	Source	Year
[1]	TR-319	Achieving Packet Network Optimization using DWDM Interfaces	BBF	2015
[2]	IEEE 802.3	IEEE Standards for Ethernet	IEEE	2012
[3]	IEEE 802.3.1-2013	IEEE Standard for Management Information Base (MIB) Definitions for Ethernet	IEEE	2013
[4]	ITU-T G.694.1	Spectral grids for WDM applications: DWDM frequency grid	ITU-T	2012
[5]	ITU-T G.694.2	Spectral grids for WDM applications: CWDM wavelength grid	ITU-T	2003
[6]	ITU-T G.709/Y.1331	Interfaces for the optical transport Network	ITU-T	2012
[7]	ITU-T G.8013/Y.1731	OAM functions and mechanisms for Ethernet based networks	ITU-T	2013
[8]	ITU-T G.805	Generic functional architecture of transport networks	ITU-T	2000
[9]	ITU-T 959.1	Optical transport network physical layer interfaces	ITU-T	2012
[10]	ITU-T Suppl. 43	Transport of IEEE 10GBASE-R in optical transport networks (OTN)	ITU-T	2011
[11]	RFC 2205	Resource ReserVation Protocol (RSVP)	IETF	1997
[12]	RFC 2578	Structure of Management	IETF	1999

		InformationVersion 2 (SMIv2)		
[13]	RFC 2961	RSVP Refresh Overhead Reduction Extensions	IETF	2001
[14]	RFC 3209	RSVP-TE: Extensions to RSVP for LSP Tunnels	IETF	2001
[15]	RFC 3471	Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description	IETF	2003
[16]	RFC 3473	Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Extensions	IETF	2003
[17]	RFC 3477	Signaling Unnumbered Links in Resource ReSerVation Protocol – Traffic Engineering (RSVP-TE	IETF	2003
[18]	RFC 3945	Generalized Multi-Protocol Label Switching (GMPLS) Architecture	IETF	2004
[19]	RFC 4201	Link Bundling in MPLS Traffic Engineering	IETF	2005
[20]	RFC 4204	Link Management Protocol (LMP)	IETF	2005
[21]	RFC 4206	Label Switched Paths (LSP) Hierarchy with Generalized Multi-Protocol Label Switching (GMPLS) Traffic Engineering (TE)	IETF	2005
[22]	RFC 4208	Generalized Multiprotocol Label Switching (GMPLS) User-Network Interface (UNI): Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Support for the Overlay Model	IETF	2005
[23]	RFC 4872	RSVP-TE Extensions in Support of End-to-End Generalized Multi-Protocol Label Switching (GMPLS) Recovery	IETF	2007
[24]	RFC 4873	GMPLS Segment Recovery	IETF	2007
[25]	RFC 4874	Exclude Routes – Extension to Resource ReserVation Protocol – Traffic Engineering (RSVP-TE)	IETF	2007
[26]	RFC 5063	Extensions to GMPLS Resource	IETF	2007

		Reservation Protocol (RSVP) Graceful Restart		
[27]	RFC 5440	Path Computation Element (PCE) Communication Protocol (PCEP)	IETF	2009
[28]	RFC 5520	Preserving Topology Confidentiality in Inter-Domain Path Computation Using a Path-Key-Based Mechanism	IETF	2009
[29]	RFC 5623	Framework for PCE-Based Inter-Layer MPLS and GMPLS Traffic Engineering	IETF	2009
[30]	RFC 5711	Node Behavior upon Originating and Receiving Resource Reservation Protocol (RSVP) Path Error Messages	IETF	2010
[31]	RFC 6002	Generalized MPLS (GMPLS) Data Channel Switching Capable (DCSC) and Channel Set Label Extensions	IETF	2010
[32]	RFC 6003	Ethernet Traffic Parameters	IETF	2010
[33]	RFC 6004	Generalized MPLS (GMPLS) Support for Metro Ethernet Forum and G.8011 Ethernet Service Switching	IETF	2010
[34]	RFC 6020	YANG – A Data Modeling language for the Network Configuration Protocol (NETCONF)	IETF	2010
[35]	RFC 6107	Procedures for Dynamically Signaled Hierarchical Label Switched Paths	IETF	2011
[36]	RFC 6241	Network Configuration Protocol (NETCONF)	IETF	2011
[37]	RFC 7139	GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks	IETF	2014

2.2 Definitions

The following terminology is used throughout this TECHNICAL REPORT.

Colored Interface	A device that modulates an ITU-T G.709 [6] framed signal onto an individual channel of the ITU-T G.694.1 [4] DWDM spectral grid or the ITU-T G.694.2 [5] CWDM frequency grid. Implicit in this definition is that the reverse process occurs on the same device.
Domain	Domain is an overloaded term in the communications industry. In this context of this document *domain* refers to: • A technology specific layer network – "the packet domain" or the "optical domain" • An ITU-T G.805 [8] administrative domain i.e. resources under the control of a single operator • Single vendor domain – a network or sub-network composed of equipment from one vendor
DWDM Network Element	Any device located in a DWDM transport network that is capable of multiplexing and demultiplexing wavelengths. An example of this could be a ROADM, Wavelength Cross Connect, or passive multiplexer/demultiplexer.
Packet Node	A device that generates packets into the optical network, e.g. an IP router, an Ethernet switch, or a POTN switch.

2.3 Abbreviations

This TECHNICAL REPORT uses the following abbreviations:

CN	Core Node
DCSC	Data Channel Switching Capability
EMS	Element Management System
EN	Edge Node
EPL	Ethernet Private Line
ERO	Explicit Route Object
GMPLS	Generalized Multiprotocol Label Switching
LMP	Link Management Protocol
LSP	Label Switched Path
MEG	Maintenance Entity Group
NMS	Network Management System
OTN	Optical Transport Network

OTU	Optical Channel Transport Unit
ROADM	Reconfigurable Optical Add/Drop Multiplexer
RSVP	Resource Reservation Protocol
RSVP-TE	Resource Reservation Protocol – Traffic Engineering
Rx	Receiver
SDN	Software-Defined Networking
SDO	Standards Developing Organization
SNMP	Simple Network Management Protocol
TE	Traffic Engineering
TR	Technical Report
Tx	Transmitter
UNI	User to Network Interface
WA	Working Area

3 Reference Architecture

3.1 Physically Separated Model Reference Architecture

Figure 1 provides a reference for the Physically Separated DWDM Interface Architecture, representing an integrated full end to end solution. Note that this reference model is derived from the architecture outlined in Figure 1 of TR-319 Base "Achieving Packet Network Optimization using DWDM Interfaces – Base", with the reference Da (not shown in Figure 1) physically located inside the DWDM Network Element. This is an integrated packet and DWDM network with the Colored Interface physically separated from the packet node.

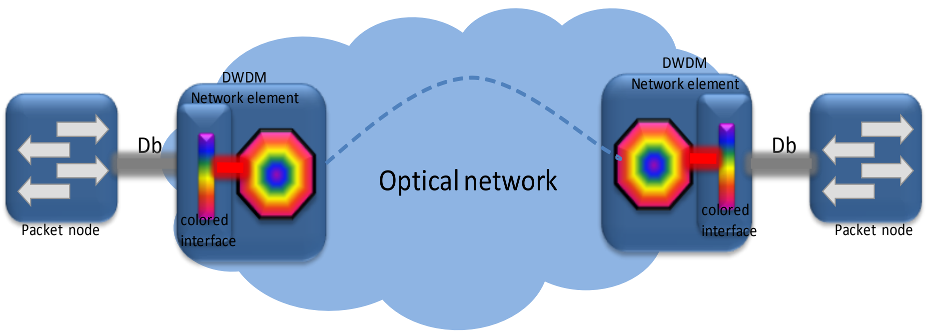

Figure 1: Physically Separated Model Architecture

The interconnection between the packet node and the DWDM network element, i.e., the reference point Db (see Figure 2), can use underlying technology based on IEEE 802.3 Ethernet [2] or ITU - T G.959.1 OTN [9]. Note in ether case, the data communication on the connection between the packet node and the DWDM network element is bi-directional. Note also that for Ethernet client interfaces, the ITU-T compliant optical signal and the G.709 frame used within the optical network are originated and terminated within the DWDM network elements.

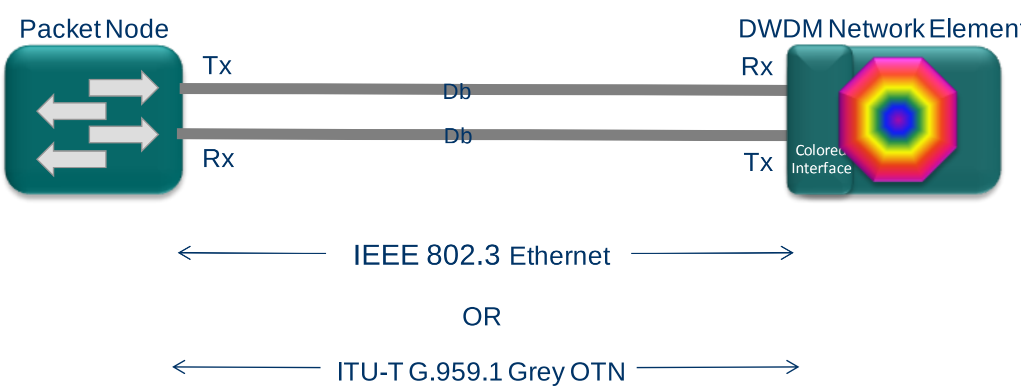

Figure 2: Interface between Packet Node and DWDM Network Element

3.1.1 Db Reference with IEEE Ethernet 802.3

The Ethernet connection between the packet node and the DWDM network element is a bidirectional channel. When the packet node is a transmitter, Ethernet frames from the packet node are sent to the DWDM network element. When the packet node is a receiver, Ethernet frames from the DWDM network element are sent to the packet node. Possible physical layers that may be used for transmission are the IEEE 802.3 [2] specifications for 10G, 40G and 100G rates. Figure 3 shows an example view of the interface between packet node and DWDM network element.

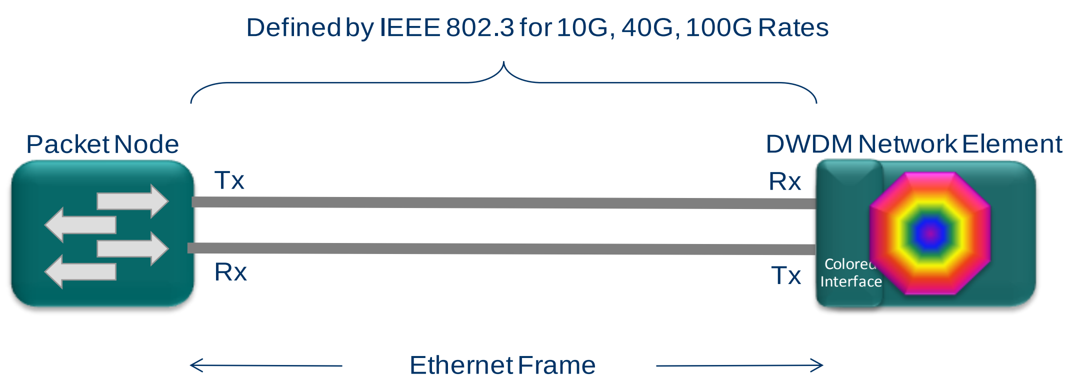

Figure 3: Ethernet Connection between Packet Node and DWDM Network Element

3.1.2 Db Reference with ITU-T OTN Interfaces

The OTN connection (Figure 4) between the packet node and DWDM network element is a bi-directional channel at G.709 [6] standard OTU2 and OTU4, and partially standardized G.Suppl.43 [10] OTU2e.

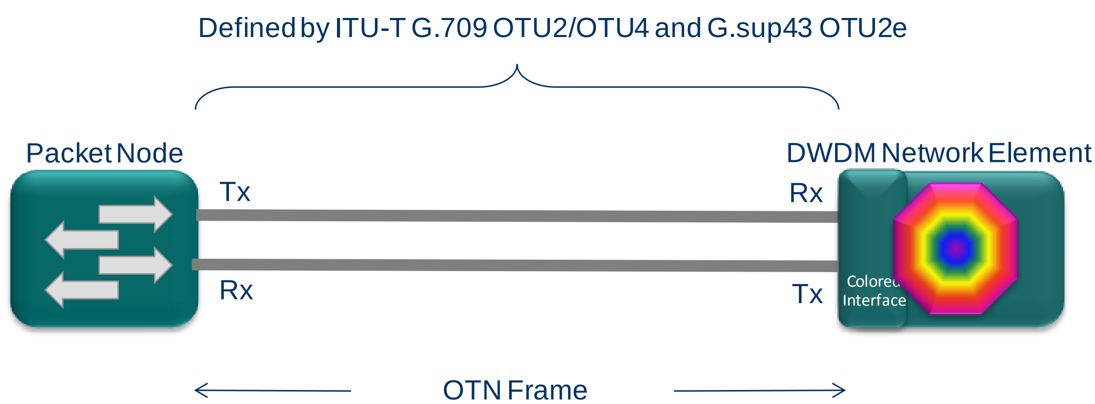

Figure 4: OTN Connection between Packet Node and DWDM Network Element

4 Nodal Requirements for Physically Separated Packet Node and DWDM Network Element

This section provides requirements only for the case when Ethernet is used as the interface between the packet node and the directly connected DWDM network element. Note that packet node and its directly connected DWDM network element can also be on OTN based interface, where the related requirements are under further study.

4.1 Data Plane

Ethernet is the most widely used data interface for packet node devices. At the same time, current OTN devices such as Transponders and Muxponders that act as the DWDM network elements support Ethernet as well. It is therefore natural to adopt Ethernet as the data path between packet node and DWDM network element.

Ethernet standards are defined by IEEE and the Ethernet connection between the packet node and DWDM network element must be compliant with these standards. The following requirements are applied to the interface between packet node and DWDM network element.

If 10GBase interface is supported between a packet node and a DWDM network element on a ROADM, the following requirements (1-3) apply:

[R-1] The packet node and DWDM network element MUST be able to support 10GBase-S using MMF fiber defined by IEEE 802.3 [2] with an operating range from 2 to 400 meters (refer to Table 52-6 of [2]).

[R-2] The packet node and DWDM network element MUST be able to support 10GBase-L using SMF fiber defined by IEEE 802.3 [2] with an operating range from 2 meters to 10 kilometers (refer to Table 52-11 of [2]).

[R-3] The packet node and DWDM network element SHOULD be able to support 10GBase-E using SMF fiber defined by IEEE 802.3 [2] with an operating range from 2 meters to 30-40 kilometers (refer to Table 52-15 of [2]).

If 40GBase interface is supported between a packet node and a DWDM network element on a ROADM, the following requirements (4-6) apply:

[R-4] The packet node and DWDM network element MUST be able to support 40GBase-SR4 defined by IEEE 802.3 [2] using MMF fiber with an operating range from 0.5 meter to 100-150 meters (refer to Table 86-2 of [2]).

[R-5] The packet node and DWDM network element MUST be able to support 40GBase-LR4 defined by IEEE 802.3 [2] using SMF fiber with an operating range from 2 meters to 10 kilometers (refer to Table 87-6 of [2]).

[R-6] The packet node and DWDM network element MUST be able to support 40GBase-FR defined by IEEE 802.3 [2] using SMF fiber with an operating range from 2 meters to 2 kilometers (refer to Table 89-5 of [2]).

If 100GBase interface is supported between a packet node and a DWDM network element the following requirements (7-9) apply:

[R-7] The packet node and DWDM network element MUST be able to support 100GBase-SR10 defined by IEEE 802.3 [2] using MMF fiber with an operating range from 0.5 meter to 100-150 meters (refer to Table 86-2 of [2]).

[R-8] The packet node and DWDM network element MUST be able to support 100GBase-LR4 defined by IEEE 802.3 [2] using SMMF fiber with an operating range from 2 meters to 10 kilometers (refer to Table 88-6 of [2]).

[R-9] The packet node and DWDM network element SHOULD be able to support 100GBase-ER4 defined by IEEE 802.3 [2] using SMMF fiber with an operating range from 2 meters to 30-40 kilometers (refer to Table 86-6 of [2]).

A packet node and its interconnected DWDM network element on a ROADM by an Ethernet link must be interoperable at the data plane according to the configuration.

[R-10] The packet node and DWDM network element MUST be interoperable to each other at a given transmission rate per configuration, with the transmit/receive characteristics compliant with IEEE 802.3 [2], ensuring that interoperability be achieved on transmitter and receivers of equipments from different vendors.

4.2 Control Plane

As shown in Figure 1, packet nodes are inter-connected across the DWDM network. In this scenario, user data from one packet node is transported to another across the network on an end-to-end data path.

A GMPLS control plane can optionally be used to establish an end-to-end TE LSP between two packet nodes across the DWDM network. Such a GMPLS TE LSP consists of three segments: the first and third are between the packet nodes and the DWDM network elements to which they are directly connected, the second one is contained within an H-LSP (RFC4206 [21]) in the DWDM network. To establish a GMPLS TE LSP, the ingress packet node initiates a GMPLS RSVP session and there is a single end-to-end GMPLS RSVP session for each GMPLS TE LSP. Refer to Appendix 1 for more detail.

[R-11] A packet node MUST be capable of initiating a GMPLS LSP using GMPLS RSVP-TE to a remote packet node through its directly connected DWDM network element according to RFC4208 [22].

A GMPLS LSP is associated with a set of traffic engineering characteristics, such as bandwidth, protection and restoration mechanism, etc. All these TE requirements are carried as GMPLS RSVP traffic engineering parameters in the GMPLS RSVP messages initiated by the ingress packet node.

In general, the optical network appears as a closed system to the packet node. In particular, while a packet node directly connects to a DWDM network element, the two may exchange routing information based on policy, and this is called an "overlay model". However they must support signaling on their UNI (User-Network interface) using GMPLS RSVP-TE in order to manage the end-to-end LSP. In the context of GMPLS UNI (RFC4208 [22]), the packet node is an Edge Node (EN) in a packet overlay network, and its directly connected DWDM network element is a Core Node (CN) in the transport network.

The signaling protocol referenced by RFC4208 on the GMPLS UNI is based on RSVP (RFC2205 [11]) with traffic engineering extension (RFC3209 [14]), along with GMPLS functions extensions RFC3473 [16]).

[R-12] The packet node and its directly connected DWDM network element MUST support GMPLS architecture according to RFC3945 [18].

[R-13] A packet node and its directly connected DWDM network element MUST support GMPLS UNI and RSVP-TE signaling protocol as per RFC4208 [22], where the packet node plays the role as an EN and the directly connected DWDM network element as a CN per RFC4208.

[R-14] The packet node and its directly connected DWDM network element MUST support GMPLS RSVP-TE as per RFC3473 [16].

RSVP-TE mechanisms can also be useful for session control.

[R-15] The packet node and its directly connected DWDM network element SHOULD support RSVP refresh mechanism per RFC2205 [11].

GMPLS RSVP-TE is a signaling protocol with a very rich set of features, where some of them are specifically useful in the overlay model interconnecting packet nodes across optical transport network.

[R-16] A packet node and its directly connected DWDM node MUST support bidirectional LSP in compliance with RFC3473 [16].

[R-17] A packet node and its directly connected DWDM node MUST support loose routes in compliance with RFC3209 [14].

[R-18] A packet node and its directly connected DWDM node SHOULD support explicit route in compliance with RFC3209 [14] and RFC3473 [16].

[R-19] A packet node and its directly connected DWDM node SHOULD support exclude route in compliance with RFC4874 [25].

The GMPLS-RSVP TE session between a packet node and a DWDM network element may be over a single physical or logical link, or a bundled link that consists of multiple physical or logical links per RFC4201 [19].

[R-20] The GMPLS-controlled interface between a packet node and its directly connected DWDM node SHOULD support link bundling per RFC4201 [19].

The network industry has been in the transition to IPv6 due to the depletion of IPv4 addresses. RSVP and GMPLS protocols (e.g., RFC3209 [14]) support both IPv4 and IPv6 addressing. In order to operate GMPLS protocols using IPv6 addressing, both packet nodes and their directly connected DWDM network elements should support IPv6.

[R-21] The packet node and its directly connected DWDM element SHOULD both be capable of supporting IPv6 addressing for GMPLS protocols.

In accordance of RFC4208 [22], the ingress packet node and its directly connected DWDM network element must share the same address space, which is used in GMPLS signaling for the end-to-end GMPLS TE LSP between the ingress packet node and egress packet node. Similarly, the egress packet node and its directly connected DWDM network element must also share the same address space.

Alternatively, the GMPLS-controlled interface between a packet node and its directly connected DWDM network element may be unnumbered.

[R-22] The GMPLS-controlled interface between a packet node and its directly connected DWDM network element SHOULD support RSVP-TE signaling on an unnumbered link in compliance with RFC3477 [17].

Both the packet node and its directly connected DWDM network element should support RSVP restart feature for the integrity of control plane.

[R-23] A packet node and its interconnected DWDM network element SHOULD support GMPLS RSVP-TE graceful restart procedure and mechanism in compliance with RFC5063 [26].

For network reliability, a packet node may have multiple connections to separate DWDM network elements in the same optical transport network, and this practice can be on the ingress packet node or/and the egress packet node.

A GMPLS RSVP-TE Path message sent by a packet node may contain an empty ERO or an ERO with loose hops. It requires the DWDM network to determine the loose segment. This can possibly be solved with the assistance of a PCE operating in stateless mode (refer to RFC4655).

To optimize the GMPLS-RSVP operation, the message reduction mechanism specified in RFC2961 [13] can be implemented, [R-24] A packet node and its directly connected DWDM network element SHOULD support the RSVP refresh overhead reduction extensions in compliance with RFC2961 [13].

The ability of communicating with a PCE requires implementing the PCE communication Protocol (PCEP) on the packet node and the DWDM network element.

[R-25] A packet node and its directly connected DWDM network element SHOULD support the PCE Communication Protocol (PCEP) in compliance with RFC5440 [27].

The PCE maintains sufficient information, including nodes, links, topology, and traffic engineering parameters in the optical transport network belonging to the operator. While a PCE requires the information for path computation to serve a Path Computation Client (PCC)'s request, security and confidentiality must not be compromised. RFC5520 [28] defines a path-key based mechanism to preserve the confidentiality of the transport network.

[R-26] If PCE is used for the establishment of GMPLS LSP, the packet node and its directly connected DWDM network element SHOULD implement the path-key based mechanism in compliance with RFC5520 [28] in order to preserve confidentiality of the optical transport network.

Since data path from ingress packet node to the egress packet node traverse the optical network core involving separate layers in data plane, information as how to use PCE to perform inter-layer traffic engineering in RFC5623 [29] may be useful.

The use of stateful PCE, e.g. in conjunction with SDN, is for further study.

4.2.1 DCSC Service using GMPLS

RFC3471 [15] describes extensions to Multi-Protocol Label Switching (MPLS) signaling required to support Generalized MPLS. For interoperability purpose, DCSC service per RFC6002 [31] using GMPLS is recommended as the default. The following sections specify some important GMPLS encoding and related handling.

4.2.1.1 Generalized Label Request

The Generalized Label Request supports communication of characteristics required to support the LSP being requested. These characteristics include: LSP Encoding Type, switching Type and Generalized Protocol Identifier. For details of DCSC label request, refer to Section 3 of RFC6002 [31].

[R-27] The packet node and its directly connected DWDM network element MUST support the format of generalized label specified in Section 3 of RFC6002.

4.2.1.1.1 LSP Encoding Type

The implementation must support the LSP Encoding Type as follows:

- Value 2 – Ethernet per RFC3471 [15].

4.2.1.1.2 Switching Type

The implementation must support the Switching type as follows:

- Value 125 – Data Channel Switching Capable (DCSC) per RFC6002 [31].

4.2.1.1.3 Generalized PID (G-PID)

The implementation must support the G-PID encoding as follows:

- Value 33 – Ethernet PHY per RFC3471 [15].

4.2.1.1.4 Generalized Label

The format of Generalized Label for DCSC based LSP is defined in RFC6002 [31].

[R-28] The packet node and its directly connected DWDM network element MUST support the format of generalized label specified in Section 3 of RFC6002.

4.2.1.2 Control Channel for DCSC Service

See Section 4.2.2 for the requirement. In addition to Section 4.2.2, the control channel must be physically separated from the data channel, in this encoding.

4.2.2 Control Channel

In GMPLS, a control channel is separated from the data channel. Section 7.18 of RFC3945 [18] specifies control channel separation.

[R-29] When GMPLS is supported, the packet node and directly connected DWDM network element MUST support separate control channel as specified in Section 7.18 of RFC3945 [18].

4.2.3 GMPLS LSP Protection and Recovery

The GMPLS control plane contains mechanisms for LSP protection and restoration. The packet node initiates the end-to-end GMPLS RSVP TE session which creates the LSP and hence is capable of signaling the LSP protection or restoration mechanism; e.g., it can include an RSVP Protection object (RFC3473 [16]) and Restart Cap Object (RFC3473) in the RSVP Path message. The directly connected DWDM network element is capable of signaling the packet node for failure from the DWDM network; e.g., it can send a RSVP PathErr message to the packet node. A packet node, on reception of the failure signal, can decide if, when and how it will recover the GMPLS LSP.

GMPLS RSVP TE message exchange between a packet node and its directly connected DWDM node enables the GMPLS LSP protection and recovery.

[R-30] The packet node MUST be able to initiate GMPLS LSP protection compliant to RFC4872 [23].

[R-31] The packet node MUST be able to initiate GMPLS LSP end-to-end restoration ("dynamic re-routing") compliant to RFC4872 [23].

[R-32] The packet node and its directly connected DWDM network element MUST support advanced RSVP-TE PathErr as per RFC5711 [30].

[R-33] The packet node and its directly connected DWDM network element SHOULD support LMP fault notification as per RFC4204 [20].

4.3 Management Plane & OAM

4.3.1 Management Plane

A packet network and its directly connected DWDM network often belong to separate network operators, and even within a single operator the two networks are usually managed by separate management stations. When a packet node directly connects to a DWDM network element, to ensure the interoperation between the two in both control plane and data plane, coordination between the two separate management systems is required. The coordination between the two management systems may involve agreement, policy, security, etc.

The SDN technology enables an integrated management system. As illustrated in Section 6 of TR-319 Base, SDN can be used for the configuration and management of packet nodes and their directly connected DWDM network elements to achieve an integrated management system for both networks. Additional SDN control details are for further study.

4.3.1.1 General

[R-34] The Management Plane MUST support functionality needed to provision, operate and maintain the Ethernet interfaces and Ethernet interface parameters regardless of the presence of a Control Plane.

[R-35] The equipment MUST be accessible from the Management Plane WITHOUT relying on a vendor-specific NMS, through standardized management models, protocols and interfaces.

[R-36] The Management Plane MUST support parameter mismatch detection and parameter mismatch reporting.

4.3.1.2 Management Plane Information Models and Data Models

The Management Plane MUST support at least one of the following management protocols:

[R-37] Simple Network Management Protocol (SNMP) to manage and monitor network elements along with Structure of Management Information Version 2 (SMIv2) (RFC2578 [12]).

[R-38] Network Configuration Protocol (NETCONF) (RFC6241 [36]) mechanisms to install, manipulate, and delete the configuration of Packet Node and DWDM/optical network devices. YANG (RFC6020 [34]) is used as data modeling language for model definitions as needed.

IEEE defines Management Information Base (MIB) Module Definitions for Ethernet (IEEE Std. 802.3.1 – 2013 [3]).

[R-39] If SNMP is supported, the Management Plane MUST support Ethernet MIB (IEEE Std. 802.3.1 – 2013[3]).

IEEE is currently working on YANG data model for managing Ethernet parameters.

[R-40] If NETCONF is supported, the Management Plane MUST support YANG (RFC6020 [34]).

4.3.2 Ethernet Performance Management and Fault Monitoring

The Ethernet OAM provides fault management and performance monitoring tools for Ethernet links (packet node to directly connected DWDM network element) and end-to-end Ethernet connection (packet node to packet node). The MEG level identifies the termination points.

[R-41] The packet node and its directly connected DWDM network element MUST support sending and receiving OAM frames as per Recommendation ITU-T G.8013/Y.1731 [7].

[R-42] The packet node and its directly connected DWDM network element MUST support performance monitoring at Ethernet interfaces, according to Section 8 “OAM functions for performance monitoring” of ITU-T G.8013/Y.1731 [7]. The performance monitoring parameters MUST be supported are as follows:

- Frame loss ratio
- Frame delay
- Frame delay variation
- Throughput

[R-43] The packet node and its directly connected DWDM network element MUST support the following performance measurements on their Ethernet interfaces according to Section 8 of ITU-T G.8013/Y.1731 [7]:

- Frame loss measurement per Section 8.1 of [7].
- Frame delay measurement per Section 8.2 of [7].
- Frame delay throughput measurement per Section 8.3 of [7].

[R-44] The packet node and its directly connected DWDM network element MUST support fault management according to Section 7 “OAM functions for fault management” of ITU-T G.8013/Y.1731 [7]. The following fault management functions MUST be supported:

- Ethernet continuity check per Section 7.1 of [7].
- Ethernet loopback per Section7.2 of [7].
- Ethernet link trace per Section 7.3 of [7].
- Ethernet alarm indication signal per Section 7.4 of [7].
- Ethernet remote defect indication per Section 7.5 of [7].
- Ethernet locked signal per Section 7.6 of [7].
- Ethernet test signal per Section 7.7 of [7].

When Ethernet is used as data path between packet node and its directly connected DWDM network element, both the packet node and the DWDM network element must monitor and react to link fault signaling as specified by IEEE 802.3 [2].

The behaviors of link fault signaling for 10G Ethernet and 40G/100G Ethernet are documented in Section 46.3.4 and Section 81.3.4, respectively, of IEEE 802.3 [2]. Note that the behaviors are the same except that the length of sequence ordered sets is different[1].

Link fault signaling operates at the Reconciliation Sublayer (RS), which is a part of the Link Layer and performs signaling mapping between Media Access Control (MAC) and Physical Layer. Local Fault (LF) indicates a fault detected on the receive data path between the remote RS and the local RS. Remote Fault (RF) indicates a fault on the transmit path between the local RS and the remote RS. When a packet node or DWDM network element receives LF or RF on its Ethernet interface, it stops sending MAC data.

If 10GBase Ethernet is supported between a packet node and a DWDM network element, the following requirement applies:

[R-45] The packet node and its directly connected DWDM network element on 10G Ethernet SHOULD be able to receive and generate link fault signaling according to IEEE 802.3 [2] (refer to Section 46.3.4 and Table 46-5).

If 40G/100G Ethernet is supported between a packet node and a DWDM network element, the following requirement applies:

[1] 10GE, the length of sequence ordered_sets is 4-byte, and for 40/100GE, the length of sequence ordered_sets is 8-byte. Refer to IEEE Ethernet Standards for details.

[R-46] The packet node and its directly connected DWDM network element on 40G/100G Ethernet SHOULD be able to receive and generate link fault signaling according to IEEE 802.3 [2] (refer to Section 81.3.4 and Table 81-5).

In the architecture considered in this part of TR-319 , the packet node and Colored Interface are physically separated, however, isolated packet networks are interconnected by the DWDM network and as such, the whole constitutes an integrated network. End-to-end LSPs from one packet network to another across the DWDM network requires protection from link faults. A link fault that occurs on an Ethernet that connects a packet node with a DWDM network element would be processed locally with action; and at the same time, it is desirable to pass the link fault signal to the remote packet node for coordination.

ITU-T G.709/Y.1331 [6] defines mechanisms that replace Ethernet local fault and remote fault sequence ordered set by a stream of 66B blocks, which are then mapped into OPUk. An ingress DWDM network element (which directly connects to a local packet node) is required to convert an Ethernet link fault signal received on the Ethernet interface to stream of 66B blocks, and an egress DWDM network element (which directly connects to a remote packet node) is required to retrieve from the stream of 66B blocks the fault signal and send Ethernet link fault signal to the remote packet node.

[R-47] The DWDM network element that directly connected to a packet node on 10G/40G/100G Ethernet SHOULD be able to replace Ethernet link fault signal received by stream of 66B blocks and vice versa, according to G.709/Y.1331 (refer to Section 17.2, 17.7.4 and 17.7.5 of [6]).

The Ethernet fault signals may be used by control plane or/and management plane with actions in order to protect the integrity of data plane's operation, and the details are out of the scope of this document.

4.4 Provisioning Data Path Connection across DWDM Network

The ultimate goal of an inter-connected packet and DWDM network is to create data path connections between packet nodes across the optical network.

To establish an end-to-end data path connection between two packet nodes across an optical network, provisioning is required on the two packet nodes and their directly connected DWDM element at the local site and remote site, respectively.

There are various methods for configuring data path on packet nodes and their directly connected DWDM network elements, where some are based on existing standards and deployment practice, and others are based on emerging new technologies. These methods include the following:

- Command Line Interface or CLI.

  CLI can be used to perform configuration at packet nodes and their directly connected DWDM elements.

- Network management system using SNMP (RFC2578 [12])

  NMS/EMS can perform configuration on packet nodes and DWDM nodes using SNMP.

- NETCONF ([36])/YANG (RFC6020 [34])

  NETCONF/YANG can perform configuration on packet nodes and DWDM nodes.

- GMPLS UNI (RFC4208 [22])

  A GMPLS UNI can be deployed between packet nodes and their directly connected DWDM element to automatically set up end-to-end data path connection between packet nodes.

- SDN

  SDN controllers can be deployed along with standards based protocols (e.g., OpenFlow and PCEP (RFC5440 [27]) to provision packet nodes and DWDM nodes.

Due to differences in deployment and technology evolvement and also in operational preferences, one or a combination of more than one of the above may be used in an implementation. In any case, coordination is required on network equipments using one or more provisioning methods.

In addition to the packet nodes and their directly connected DWDM network elements, provisioning is also required in the DWDM network, where the detail is out of scope of TR-319 Part-B.

4.5 SDN and Interface to SDN Controller

SDN controllers may optionally be deployed when interconnecting packet network and DWDM network to perform the following tasks:

1) Provision end-to-end data path between two packet nodes across a DWDM network (refer to Section 4.4).

2) Support integrated management system (refer to Section 4.3.1).

In either case, packets nodes and their directly connected DWDM network elements need to implement standards based north-bound interfaces to SDN controllers.

[R-48] Packet nodes and their directly connected DWDM network elements SHOULD support standards-based interface to SDN controllers.

Appendix 1 GMPLS UNI Signaling Model

Figure 5 illustrates a GMPLS-RSVP signaling example using a two-step procedure as described in RFC4208 [22]. There is a single end-to-end RSVP session between two packet nodes EN1 and EN2 across the DWDM network. The end-to-end RSVP session consists of three hops:

- The first hop is the GMPLS UNI between packet node EN1 and its directly connected DWDM network element CN1.
- The last hop is the GMPLS UNI between packet node EN2 and its directly connected DWDM network element CN4.
- The middle hop is carried by and within a H-LSP (RFC4206 [21]) between ingress and egress DWDM network elements CN1 and CN4, and it falls in the DWDM network. There are different ways to make the H-LSP between CN1 and CN4 in the DWDM network, including via management plane, using GMPLS signaling (RFC6107 [35]), etc.; specifying a particular means is beyond the scope of this document.

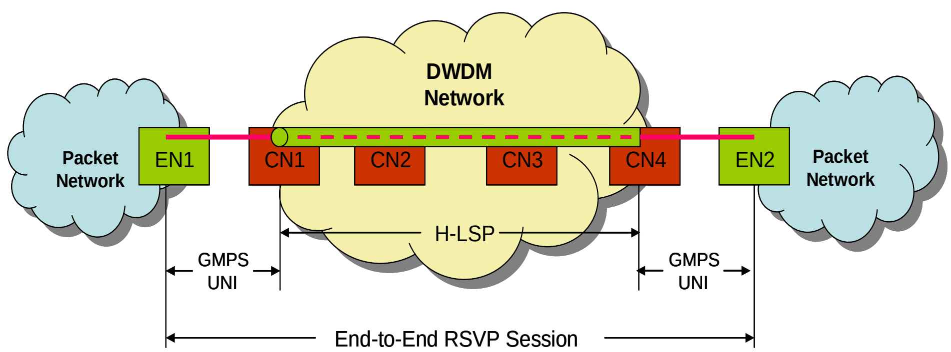

Figure 5 GMPLS UNI Signaling Model

Appendix 2 GMPLS RSVP TE Encoding Examples

The following are some encoding examples when a packet node sends a GMPLS RSVP TE Path message to the directly connected DWDM network element on an Ethernet interface.

A.2.1 Label Request

In the GMPLS RSVP-TE Label Object, it is required to specify the following parameters (Refer to RFC3471 [15]):

- LSP Encoding
- Switching Type
- G-PID

Depending on the services and underlying data plane, there are different combinations of the above. For the use case described in this document, the default encoding for GMPLS RSVP-TE

Path message sent by a packet node to its directly connected DWDM network element is described in Section 4.2.1. Other encoding may also be used such as the following examples:

- Ethernet (on link between packet node and DWDM node) – end-to-end LSP:
  - LSP Encoding: G.709 Optical Channel (13)
  - Switching Type: DCSC (125)
  - G-PID: Ethernet (33)

See Section 4.2.2 for the requirement. In addition to Section 4.2.2, the control channel must be physically separated from the data channel with this encoding.

- Ethernet (on link between packet node and DWDM node) – EVPL service (Refer to RFC6004 [33]):
  - LSP Encoding: Ethernet (2)
  - Switching Type: EVPL (30)
  - G-PID: Ethernet (33)

See Section 4.2.2 for the requirement. In addition to Section 4.2.2, the control channel must be physically separated from the data channel with this encoding. Optionally, the control channel may be carried logically separated from data channel via separate VLAN per RFC6004 [33].

- OTN (on link between packet node and DWDM node) – end-to-end LSP (Refer to RFC7139 [37]):
  - LSP Encoding: G.709 ODUk (12)
  - Switching Type: OTN-TDM (110)
  - G-PID:
    - G.709 ODU-2.5G (47)
    - G.709 ODU-1.25G (66)
    - G.709 ODU-any (67)

See Section 4.2.2 for the requirement. In addition to Section 4.2.2, the control channel must be physically separated from the data channel with this encoding.

A.2.2 Bandwidth Encoding

Bandwidth encodings are carried in SENDER_TSPEC object and FLOWSPEC object and are represented as 32-bit numbers in IEEE floating point format with granularity of bytes per second.

The related parameters are technology dependent, for example:

- For non-packet and non-OTN based GMPLS LSP refer to Section 3.1.2 of RFC3471 [15].
- For Ethernet-based GMPLS LSP refer to Section 4.1 of RFC6003 [32].
- For OTN-based LSP refer to Section 7 of RFC7139 [37].

A.2.3 Generalized Label

The DWDM network element that receives a GMPLS RSVP Path message may return a Resv message to the directly connected packet node, which contains a Generalized label Object (Section 2.3 of RFC3473 [16]), where the Generalized Label represents a generic MPLS label. Refer to Section 3.2 of RFC3471 [15] for details.

Alternatively, a packet label (Section 4.1 of RFC3209 [14]) may be used within the Resv message sent by the DWDM network element back to the packet node. Refer to Section 2.3.1 of RFC3473 [16].

A.2.4 Upstream Label

Bidirectional LSP requests must include an Upstream Label in the GMPLS RSVP Path message. An Upstream Label object has the same format as the generalized label. Refer to Section 3 of RFC3473 [16].

A.2.5 Session Object

For IPv4 network, the Session Object is LSP_TUNNEL_IPv4 Session Object, and its encoding is as follows (Section 4.6.1 of RFC3209 [14]):

- IPv4 tunnel end point address – the IPv4 address of the remote packet node.
- Extended tunnel ID – all zeros or an IPv4 address of the local packet node.
- Tunnel ID – assigned by the local packet node uniquely for the LSP.

For IPv6 network, the Session Object is LSP_TUNNEL_IPv6 Session Object, and its encoding is as follows (Section 4.6.1.2 of RFC3209 [14]):

- IPv6 tunnel end point address – the IPv6 address of the remote packet node.
- Extended tunnel ID – all zeros or an IPv6 address of the local packet node.
- Tunnel ID – assigned by the local packet node uniquely for the LSP.

A.2.6 Session Template Object

For IPv4 network, the Session Template Object is LSP_TUNNEL_IPv4 Sender Template Object, and its encoding is as follows (Section 4.6.2.1 of RFC3209 [14]):

- IPv4 tunnel sender address – the IPv4 address of the local packet node.
- LSP ID – a 16-bit identifier assigned by the local packet node.

For IPv6 network, the Session Template Object is LSP_TUNNEL_IPv6 Sender Template Object, and its encoding is as follows (Section 4.6.2.2 of RFC3209 [14]):

- IPv6 tunnel sender address – the IPv6 address of the local packet node.
- LSP ID – a 16-bit identifier assigned by the local packet node.

End of Broadband Forum TECHNICAL REPORT TR-319 Part-B

