TECHNICAL REPORT

TR-319 Part A

Achieving Packet Network Optimization using DWDM Interfaces - Physically Integrated Model

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Issue History

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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), e.g. integrated colored optical transceivers in routers and packet switches, allow for better integration at the data plane and for better control and management integration. The integration of DWDM interfaces into IP routers or packet switches (Packet Nodes), allows service providers to better integrate their networks, taking advantage of these new developments in optical and control plane technologies.

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 A specifies the Architecture and Requirements of the Physically Integrated Model, i.e. for the integration of colored optical transceivers (Colored Interfaces) into Packet Nodes. TR-319 Part A is a companion to the TR-319 Framework.

1 Purpose and Scope

1.1 Purpose

Network operators have identified better integration of their packet and DWDM networks as a way to address growing traffic demands, increase efficiency and potentially reduce OPEX. Such integration can occur at one or more of the Data, Control or Management Planes in the network.
Technology advancements (at all levels of Data, Control and Management Plane), e.g. integrated DWDM optical transceivers in routers and packet switches, allow for better integration at the Data Plane and for better control and management integration. The integration of DWDM interfaces into IP routers or packet switches (Packet Nodes), allows service providers to optimize their networks, taking advantage of these advancements in optical/Data, Control, and Management Plane technologies.
TR-319 specifies requirements for interoperable multi-vendor solutions that enable this integration, for the benefit of consumers and suppliers of broadband services alike.

TR-319 Part A specifies the Architecture and Requirements of the Physically Integrated Model, i.e. for the integration of colored optical DWDM transceivers (Colored Interfaces) into Packet Nodes, including aspects of the Control and Management Planes associated with those deployments.
Integrated packet/optical networks and network equipment are based on a variety of protocols and functionalities from different Standards Developing Organizations (SDO). TR-319 Part A identifies the set of specifications that are necessary for multi-vendor interoperable implementations of integrated packet optical networking equipment.

Physical layer interoperability is a fundamental requirement for the interconnection of network equipment. One key component of TR-319 Part A is ITU-T G.698.2 [3] for the physical (optical) layer which enables the usage of multi-vendor interoperable DWDM transceiver technology for optical interconnections.
A Control Plane can allow easier operation of the network. The, optional, Control Plane requirements specified in TR-319 Part A are based on the IETF's GMPLS [16].
Standard data models of management information are necessary to configure and manage equipment and networks, and TR-319 Part A specifies those necessary for the Physically Integrated Model.
Software-Defined Networking (SDN) is emerging as a viable alternative and complement to contemporary Management and Control Plane solutions, and some details of its application to integrated optical and packet networks are provided.

1.2 Scope

TR-319 Part A defines the Architecture and Nodal Requirements for the Physically Integrated Model, enabled by the integration of Colored Interfaces into Packet Nodes including:

a. The Data Plane as defined by Recommendations ITU-T G.694.1 [2], G.698.2 [3], and G.709 [4]. TR-319 Part A refers to ITU-T for the Data Plane specifications, and nothing herein is intended to redefine any ITU-T architecture, interfaces, physical layer specifications or parameters defined for optical networks.

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. TR-319 Part A refers to relevant ITU-T and IETF management documents and specifications for definitions of e.g., data models and protocols.

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]	ITU-T G.694.1	Spectral grids for WDM applications: DWDM frequency grid	ITU-T	2012
[3]	ITU-T G.698.2	Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces	ITU-T	2009
[4]	ITU-T G.709	Interfaces for the optical transport Network	ITU-T	2012
[5]	ITU-T G.798	Characteristics of optical transport network hierarchy equipment functional blocks	ITU-T	2012
[6]	ITU-T G.872	Architecture of optical transport networks	ITU-T	2012
[7]	ITU-T G.872 Amd.1	Architecture of optical transport networks - Amendment 1	ITU-T	2013
[8]	ITU-T G.874	Management Aspects of Optical Transport Network Elements	ITU-T	2013
[9]	ITU-T G.874.1	Optical transport network: Protocol-neutral management information model for the network element view	ITU-T	2012
[10]	ITU-T G.7710/Y.1701	Common Equipment Management Function Requirements	ITU-T	2012
[11]	ITU-T Suppl. 43	Transport of IEEE 10GBASE-R in optical transport networks (OTN)	ITU-T	2011

[12]	RFC 2578	Structure of Management Information Version 2 (SMIv2)	IETF	1999
[13]	RFC 3209	RSVP-TE: Extensions to RSVP for LSP Tunnels	IETF	2001
[14]	RFC 3411	An Architecture for Describing Simple Network Management Protocol (SNMP) Management Frameworks	IETF	2002
[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	Signalling Unnumbered Links in Resource ReSerVation Protocol – Traffic Engineering (RSVP-TE	IETF	2003
[18]	RFC 3591	Definitions of Managed Objects for the Optical Interface Type	IETF	2003
[19]	RFC 3945	Generalized Multi-Protocol Label Switching (GMPLS) Architecture	IETF	2004
[20]	RFC 4204	Link Management Protocol (LMP)	IETF	2005
[21]	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
[22]	RFC 4209	Link Management Protocol (LMP) for DWDM optical line systems	IETF	2005
[23]	RFC 4328	Generalized Multi-Protocol Label Switching (GMPLS) Signaling Extensions for G.709 Optical Transport Networks Control	IETF	2006
[24]	RFC 4874	Exclude Routes – Extension to Resource ReserVation Protocol – Traffic Engineering (RSVP-TE)	IETF	2007
[25]	RFC 6020	YANG - A Data Modeling Language	IETF	2010

		for the Network Configuration Protocol (NETCONF)		
[26]	RFC 6205	Generalized Labels for Lambda Switch-Capable (LSC) Label Switching Routers	IETF	2011
[27]	RFC6241	Network Configuration Protocol (NETCONF)	IETF	2011

2.2 Definitions

The following terminology is used throughout this Technical Report.

Black Link	A Black Link, as used in ITU-T G.698.2 [3], provides a network media channel (optical path) of a defined center frequency to support single-channel optical interfaces from different vendors. The network providing a Black Link can be composed of amplifiers, filters, add-drop multiplexers which may be from a different vendor. Recommendation ITU-T G.698.2 provides optical parameter values for physical layer interfaces.
Colored Interface	A device that modulates a ITU-T G.709 framed signal onto an individual channel of the ITU-T G.694.1 (DWDM) spectral grid or the ITU-T G.694.2 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 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.
Intra-Domain	Inside an administrative domain. TR-319 specifies requirements to enable multi-vendor solutions for a single administrative domain only.
IPoverDWDM	Integration of DWDM/colored interfaces into IP routers, including, specifically, transport of Ethernet encapsulated IP datagrams in ITU-T G.709 frames over a DWDM network (see section 4.1.3.1 Payload Mapping)..
Network Media Channel	Network Media Channel as defined in ITU-T G.872 [6].
Optical Channel	Optical Channel (OCh) as defined in ITU-T G.872 [6].
Packet Node	A device that generates packets into the optical network, e.g. an IP router, an Ethernet switch, or a POTN switch.
Pre-FEC BER	The raw Bit Error Ratio (BER) before the FEC has been applied.

2.3 Abbreviations

This Technical Report uses the following abbreviations:

3R	Re-amplification, Re-shaping, Re-timing
BER	Bit Error Ratio
CWDM	Coarse Wavelength Division Multiplexing
C-NMS	Common - Network Management System
CP	Control Plane
DWDM	Dense Wavelength Division Multiplexing
EFEC	Enhanced Forward Error Correction
EMS	Element Management System
ERO	Explicit Route Object
FEC	Forward Error Correction
FRR	Fast Reroute
GFEC	Generic Forward Error Correction
GFP	Generic Framing Procedure
GMPLS	Generalized MultiProtocol Label Switching
IFG	Inter-Frame Gap
IPG	Inter-Packet Gap
LMP	Link Management Protocol
LSP	Label Switched Path
MIB	Management Information Base
NBI	North Bound Interface
NMS	Network Management System
NE	Network Element
NNI	Network to Network Interface
NRZ	Non-Return to Zero
OA	Optical Amplifier
OADM	Optical Add-Drop Multiplexer
OAM	Operations, Administration and Maintenance
OCC	Overhead Communications Channel
OCN	Overhead Communications Network
OCh	Optical Channel
OCh-O	OCh-Overhead
ODU	Optical Channel Data Unit

OD	Optical Demultiplexer
OEO	Optical-Electrical-Optical
OID	Object Identifier
OM	Optical Multiplexer
OPU	Optical Channel Payload Unit
OSC	Optical Supervisory Channel
OSNR	Optical Signal to Noise Ratio
OTN	Optical Transport Network
OTU	Optical Channel Transport Unit
P	Provider
PE	Provider Edge
POTN	Packet Optical Transport Network
POP	Point Of Presence
PSI	Payload Structure Identifier
PSN	Packet Switching Network
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
TIM	Trace Identifier Mismatch
TTI	Trail Trace Identifier
TR	Technical Report
Tx	Transmitter
UNI	User to Network Interface
WG	Working Group

3 Reference Architecture

3.1 Physically Integrated Model Reference Architecture

Figure 1 provides a reference for the architecture of the Physically Integrated Model, representing an integrated full end to end solution. As compared to the architecture outlined in Figure 1 (Reference Architecture) of TR-319 [1] it can be seen that the Colored Interface is now physically integrated into the packet node.

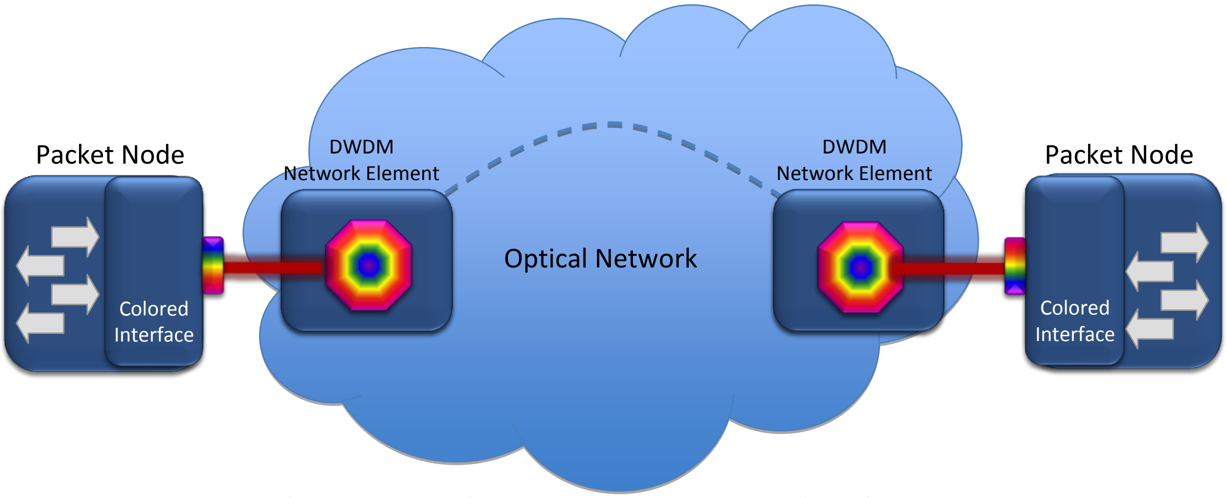

Figure 1: Physically Integrated Model Architecture

This Model uses single channel optical interfaces within the Packet Node to connect the Packet Node directly to DWDM Network Elements. The ITU-T G.709 [4] frame as well as the wavelength are both originated and terminated physically within the Packet Node. In the transmit direction, this wavelength can be immediately multiplexed into a DWDM Layer 0 (L0) network in the DWDM Network Element. In the receive direction, it is only optically demultiplexed by the DWDM Network Element before handed to the Packet Node. Any FEC algorithm that is applied will be run within the Packet Node before handing up to a higher layer. Figure 2 below shows a single-ended view including the ITU-T G.698.2 [3] reference points.

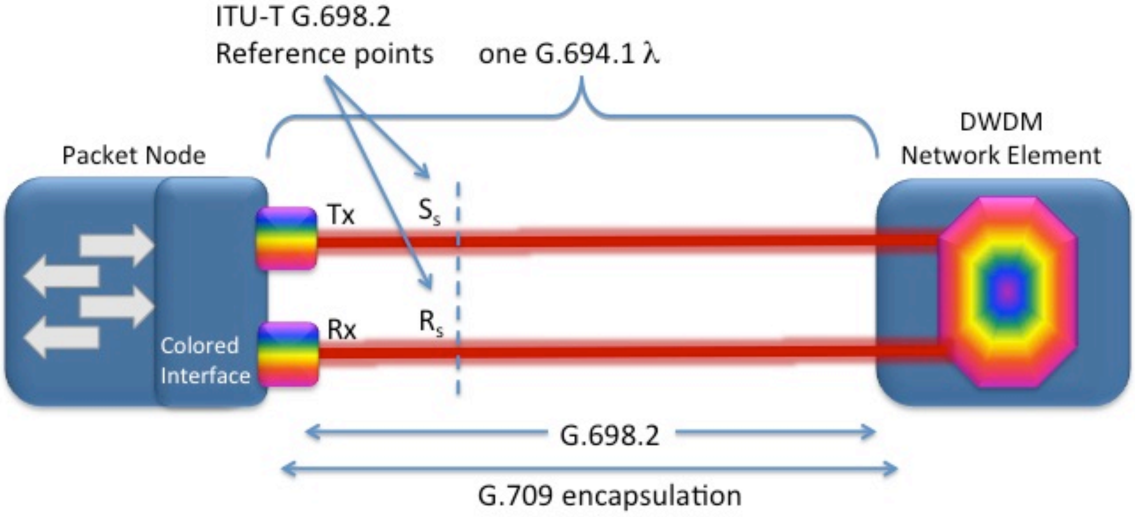

Figure 2: Physically Integrated Model Reference Points

This document specifies how to connect single channel optical interfaces on Packet Nodes to the Optical Multiplexing [OM] component of DWDM network elements. Communication between Packet Nodes is overwhelmingly bi-directional and so we specify linear bi-directional Packet Node to DWDM connection configurations.

The Model used in this document is intended to be consistent with the “Black Link” approach used in ITU-T G.698.2 [3] from which Figure 3 below is taken.

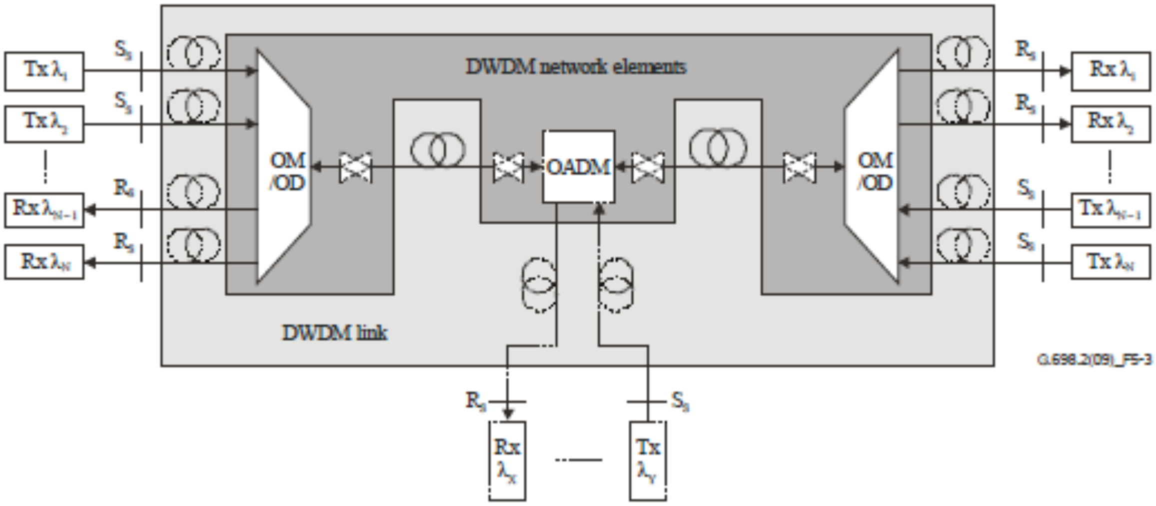

Figure 3: Optical connection reference points (Source: ITU-T G.698.2 [3])

This document specifies Nodal Requirements for a Packet Node to support the Physically Integrated Model. The reference points as outlined in ITU-T G.698.2 [3], R_S and S_S are specified in Figure 3 and are located between the Packet Node and the DWDM Network Element.

4 Nodal Requirements for Packet and DWDM/Optical integration

4.1 Data Plane

Packet traffic is carried over the OCh's of the DWDM network using OTUk framing specified in ITU-T G.709 [4]. Client signals can be transported transparently over the OTN. The ITU-T G.709 [4] OTN frame provides OAM and Path monitoring capabilities and a comprehensive signal mapping and multiplexing structure.

The ITU-T G.709 [4] OTN frame includes transport overhead that provides Operation, Administration, and Maintenance (OAM) capabilities, Path Monitoring (PM) and Forward Error Correction (FEC). The FEC reduces impact of transmission errors on noisy links, which enables the deployment of longer optical spans[1]. Functionally standardized OTUkV frame structures defined in ITU-T G.709 [4] provide support for alternative FECs including non-standard FECs for which multi-vendor interoperability may not be guaranteed.

Packet Nodes are expected to support the ITU-T G.709 [4] framing as detailed in the requirements below.

4.1.1 Deployment Expectations

The following are expectations regarding the solutions in which the TR-319 Part A compliant equipment (specifically the Packet Node integrating the Colored Interface) will be deployed:

1) The solution must support operation within an optically transparent transmission reach of several hundreds of kilometers, in an amplified network, without 3R.
2) The solution should support transmission reach of 1000 kilometers.
3) The solution must support 100G.
4) The solution must support 10G.

4.1.2 Black Link

ITU-T G.698.2 [3] specifies optical parameters and application codes for multi-vendor transceiver interoperability. Support for 100Gbit/s application codes and optical parameters are work in progress at the ITU-T in time of this writing.

Requirements for the 100G DWDM interfaces are provided in the Annex A and support the Deployment Expectations section 4.1.1 above.

4.1.3 Interface Requirements

This section specifies requirements for the Colored Interfaces in Packet Nodes. According to the definition of Colored Interface in section 2.2 of this document, we specify requirements on both the optical and electrical signals embodied in it. For brevity we refer the requirements to the Packet Node, integrating the Colored Interface.

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[1] "A G.709 Optical Transport Network Tutorial", Guylain Barlow, JDSU.

4.1.3.1 Payload Mapping

The ITU-T G.709 [4] OTN frame consists of the overhead, the payload, and the FEC. The OTN overhead has three parts: the Optical channel Transport Unit (OTU) overhead, Optical channel Data Unit (ODU) overhead, and Optical channel Payload Unit (OPU) overhead. The OPUk overhead consists of payload structure identifier (PSI) which includes the payload type (PT). The OTN supports transparent transport of packet based protocols such as Ethernet.

[R-1] The Packet Node MUST support OTN framing and Forward Error Correction as per ITU-T G.709 [4].

[R-2] The Packet Node SHOULD support mapping of 10GBASE-R Ethernet into OPU2 by GFP procedure as per ITU-T G.709 [4] clause 17.4.

[R-3] The Packet Node MUST support mapping of 10GBASE-R Ethernet into OPU2e by bit synchronous mapping procedure as per ITU-T G.709 [4] clause 17.2.4.
Note: For many applications, bit-for-bit Ethernet PCS (physical coding sublayer) transparency is a requirement and the preamble and Inter-Frame Gap (IFG) must be carried intact over a transport network.

[R-4] The Packet Node SHOULD support mapping of OPU2 into ODU2.

[R-5] The Packet Node MUST support mapping of OPU2e into ODU2e.

[R-6] The Packet Node MUST support ODU2e bit rate, according to clause 12.2.2/ ITU-T G.709.

[R-7] The packet node MUST support OTU2e signal according to clause 7.1/ITU-T Supplement 43 to G series [11]: The resulting OTU-like OTU2e signal must be clocked at a nominal bit rate of 11.0957 Gbit/s, as opposed to the standard OTU2 nominal bit rate of 10.709225316 Gbit/s.

Note(s):
1) ITU-T G.Sup43 indicates that the 'OTU-like' OTU2e signal has a nominal bit rate of 11.0957 Gbit/s, but does not define a standard OTU type and bit rate. There is no guarantee for multi-vendor interoperability for functionality defined in a Supplement.
2) At the time of this writing, there is no standard signal specified in ITU-T G.709 for the transport of ODU2e, and there is no application code specified in ITU-T G.698.2 that supports 11.0957Gbit/s bit rates. For non-standard signals, multi-vendor interoperability cannot be guaranteed.

[R-8] The packet node SHOULD support OTU2 according to ITU-T G.709 [4].

4.1.3.2 Transmitter and Receiver characteristics

[R-9] The Packet Node MUST support single-channel interfaces with application codes as specified in ITU-T G.698.2 [3].

Note: The parameters for DWDM applications include power at Ss and OSNR at Rs interface points. The optical reach of a system is a function of the combined characteristics of the transmitter, the black link and the receiver. The major components for optical system reach are: the optical path between the Ss and Rs reference points, and the capabilities of the transmitter and receiver.

[R-10] The Packet Node MUST be able to transmit and receive optical wavelengths conforming to the DWDM frequency grid as per ITU-T G.694.1 [2].

[R-11] The Packet Node MUST support NRZ modulation for 10G as per ITU-T G.698.2 [3].

4.1.3.3 Black Link transfer characteristics

[R-12] The Packet Node MUST support single-channel optical interfaces and related transfer characteristics according to ITU-T G.698.2 [3].

4.2 Control Plane

GMPLS signaling messages for establishing LSPs contain generalized label request which contain LSP type and LSP payload type. Section 7/RFC 3945 [19] provides general signaling.

Lambda LSPs are used as 'tunnels' between Packet Nodes. The wavelength used for the LSP is established by signaling or configuration in the Packet Nodes and the DWDM Network.

4.2.1 Lambda LSP Request

Section 7.1/RFC 3945 [19] specifies how to request an LSP. A lambda LSP is established by sending a PATH/Label Request message from packet node to the destination. This message contains a Generalized Label Request with the type of LSP (i.e., the layer concerned), and its payload type. An Explicit Route Object (ERO) may be added to the message.

The requested bandwidth is encoded in the RSVP-TE SENDER_TSPEC object. The PATH message may also contain other TLVs.

The DWDM Network Element (downstream node) will send back a Resv/Label Mapping message including one Generalized Label object/TLV that can contain Generalized Labels.

4.2.2 Generalized Label Request

RFC 3471 [15] describes extensions to Multi-Protocol Label Switching (MPLS) signaling required to support Generalized MPLS.

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. It is desirable to select the values to provide interoperability.

4.2.2.1 LSP Encoding Type

The support for LSP Encoding Types is to be as follows:

- Value 8 – "Lambda (photonic)" must be supported, as specified in RFC3471 [15]
- Value 13 – "G.709 Optical Channel" must be supported, as specified in RFC4328 [23], and is the default type.

4.2.2.2 Switching Type

Switching type Indicates the type of switching that should be performed on a particular path. Code-points for switching type: Value 150 - Lambda-Switch Capable (LSC).

4.2.2.3 Generalized PID (G-PID)

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

- "G.709 OTUk(v)" code point 48 as specified in RFC4328 [23], and this is the default.
- "Unknown" code point 00, as specified in RFC3471 [15].

Note: Additional code-points for the Generalized PID are located in section 3.1.1/RFC 3471 [15], and RFC4328 [23].

4.2.2.4 Generalized Label

The generalized label for lambda LSPs identify wavelength and only carries a single level of label i.e., it is non-hierarchical.

ITU-T DWDM grids specified in G.694.1 [26] are based on nominal central frequencies. RFC 6205 [26] defines Lambda label format that is compliant with ITU-T DWDM grids. The DWDM wavelength label format for Lambda LSPs are specified in 3.2/RFC 6205 [26].

[R-13] The Packet Node and directly connected DWDM Network node MUST support DWDM wavelength label format for Lambda LSPs in compliance with 3.2/RFC 6205 [26].

4.2.3 Bandwidth Encoding

Bandwidth encodings are carried in the SENDER_TSPEC and FLOWSPEC objects. See section 3.1.2/RFC 3471 [15] for details.

Bandwidth encodings are carried in 32 bit number in IEEE floating point format (the unit is bytes per second). The format is generic and allows LSP request with any bandwidth size. For non-packet LSPs (e.g. lambda LSP) the bandwidth allocation for LSPs be performed only in discrete units (e.g. 10G or 40 G or 100G payload).

Note: The bandwidth encoding of the LSP only include Ethernet payload. ITU-T G.709 [4] frame overhead and forward error correction are not included.

4.2.4 Nodal Requirements

If a GMPLS-based control plane is used, the following requirements apply:

[R-14] The Packet Node and directly connected DWDM Network Element MUST support Generalized Multiprotocol Label Switching (GMPLS) User-Network Interface (UNI): Resource Reservation Protocol-Traffic Engineering (RSVP-TE) Support for the Overlay Model in compliance with RFC 4208 [21] [2].

[R-15] The Packet Node and directly connected DWDM Network Element MUST support GMPLS RSVP-TE in compliance with RFC 3473 [16].

[R-16] The Packet Node and directly connected DWDM Network Element MUST support lambda LSP setup using the code points specified in section 4.24.2.2 of this document (generalized label request).

Bidirectional LSPs have the same traffic engineering requirements including fate sharing, protection, restoration, and resource requirements (e.g., latency and jitter) in each direction. See section 4/RFC 3471 [15] for details. The GMPLS RSVP-TE extensions for setting up a Bidirectional LSP are discussed in section 3/RFC3473 [16]. The Bidirectional LSP setup is indicated by the presence of an UPSTREAM_LABEL Object in the PATH message.

[R-17] The Packet Node and directly connected DWDM Network Element MUST support bidirectional LSPs in compliance with RFC 3473 [16].

[R-18] The Packet Node and directly connected DWDM Network Element MUST support Loose routes in compliance with RFC 3209 [13].

[R-19] The Packet Node and directly connected DWDM Network Element SHOULD support explicit routes in compliance with RFC 3209 [13] and RFC 3473 [16].

[R-20] The Packet Node MUST support Exclude Routes in compliance with RFC 4874 [24].

The directly connected DWDM Network Element may not have an IP address. Using unnumbered links in GMPLS RSVP-TE signaling address the issue (see section 3/RFC 3945 [19]).

[R-21] The Packet Node and directly connected DWDM Network Element SHOULD support GMPLS RSVP-TE signaling with unnumbered link in compliance with RFC 3477 [17].

4.2.5 Control Channel Separation

In GMPLS, a control channel is separated from the data channel. Section 7.18/RFC 3945 [19] specifies control channel separation.

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[2] Note: In the GMPLS UNI context, the Packet Node plays the role as of an EN (Edge Node) and the DWDM Network Element as of a CN (Core Node). Refer to RFC 4208 [21] for details of functions of EN and CN respectively.

[R-22] When GMPLS is supported, the Packet Node and directly connected DWDM Network Element MUST support separate control channel as specified in section 7.18/RFC 3945 [19].

4.3 Management Plane & OAM

4.3.1 General

[R-23] The Management Plane MUST support functionality needed to provision, operate and maintain the DWDM interfaces and DWDM interface parameters regardless of the presence of a Control Plane.

[R-24] The equipment MUST be accessible from the Management Plane WITHOUT relying on a vendor-specific NMS, through standardized management models, protocols and interfaces.

As the TR-319 Architecture supports a number of different applications, including point-to-point and Packet Node back-to-back applications over passive optical networks, an assumption about the OCh subnetwork and Optical Channel-Overhead (OCh-O) carriage cannot be made.

[R-25] For equipment that supports connection to an ITU-T G.872 [6] compliant OCh subnetwork, the following requirement applies:

At the interface between the Colored Interface and the DWDM Network Element, the Optical Channel-Overhead (OCh-O) MUST be supported across an Overhead Communications Channel (OCC) within an Overhead Communication Network (OCN), according to ITU-T G.872 Amd1 [7].

[R-26] The Management Plane MUST support parameter mismatch detection and parameter mismatch reporting.

Service Providers and large enterprises may use Trail Trace Identifiers (TTI) to determine if the end points of a circuit are correct. It is used to ensure proper fiber connections between network elements or to detect wrong connections between network elements. Generally, if an unexpected TTI string is received, this may raise a Trace Identifier Mismatch (TIM) alarm. Alternatively, the TTI string value can be reported. Per ITU-T G.709 [4], TTI can be on the OTUk and ODUk layers.

[R-27] The Packet Node Colored Interface MUST support Trail Trace Identifier on OTU and ODU layers, per clause 15.2/ITU-T G.709 [4].

4.3.2 Management Plane Information Models and Data Models

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

[R-28] Simple Network Management Protocol (SNMP) to manage and monitor network elements along with Structure of Management Information Version 2 (SMIv2) (RFC 2578 [14]).

[R-29] Network Configuration Protocol (NETCONF) (RFC6241 [27]) mechanisms to install, manipulate, and delete the configuration of Packet Node and DWDM/optical network devices. YANG (RFC 6020) is used as data modeling language for model definitions as needed.

If SNMP is supported, the following MIBs SHOULD be supported:

Note: The work to extend the MIB RFC 3591 [18] to support the optical parameters, specified in ITU-T G.698.2 [3] and application identifiers specified in ITU-T G.874.1 [9], is in development in the IETF. ITU-T's protocol neutral information model is used as a base for defining protocol specific information models and is being referenced by IETF to define a data model.
The MIB module is used for Optical Parameter monitoring or configuration of the endpoints of the Colored Interfaces.

[R-30] If NETCONF is supported, the Management Plane MUST support YANG (RFC6020 [25]).

Note: The work to define YANG model for managing optical parameters associated with DWDM as described in ITU-T G.698.2 [3] is in development in the IETF. NETCONF with YANG data models can be used for configuration of lambda LSPs. It can also be used to support SDN for integrated management.
TR-319 references IETF for information and data models for both SNMP and YANG.

4.3.3 Transmitter-Side (Ss)

[R-31] The Management Plane of Packet Node SHOULD support RFC 4209 [22] Link Management Protocol for DWDM optical line system for the colored interface..

[R-32] The Management Plane of the Packet Node MUST support configuring transmitter power levels (power management) on the colored interface.

[R-33] The Management Plane of the Packet Node MUST support setting the center frequency for the transmitter laser.

4.3.4 Receiver-Side (Rs)

[R-34] The Management Plane of the Packet Node MUST support per interface counters per section 4.3.5 (Performance Management).

4.3.5 Performance Management of DWDM Interfaces

[R-35] The Packet Node MUST support performance monitoring at Colored Interfaces, according to section 10 "Performance management" of ITU-T G.874 [8].

Performance monitoring parameters MUST be supported for OTUk and ODUk, according to Table 10-1 of ITU-T G.874 [8]:

- OTUk: The Management Plane MUST support the following parameters for OTUk:
    - If FEC is enabled, number of corrected bit errors (FECCorrErr)
    - The following parameters must be supported for monitoring:
        - Severely Errored Seconds (SES)
        - Unavailable Seconds (UAS)
        - Background Block Error (BBE)

- ODUk: The Management Plane MUST support the following parameters for ODUk for monitoring:
    - Severely Errored Seconds (SES)
    - Unavailable Seconds (UAS)
    - Background Block Error (BBE)

[R-36] The Packet Node Colored Interface MUST support Performance monitoring over time, in both 15 minute and 24 hour intervals in accordance with ITU-T G.874 [8] and ITU-T G.7710/Y.1701[10]:

- The 15 minutes MUST be aligned with the quarter of an hour as required by ITU-T G.7710/Y.1701 [10].
- The 24 hour interval MUST be configurable, and start by default at midnight, as required by ITU-T Rec G.7710/Y.1701 [10].

[R-37] The following parameters MAY be supported for monitoring at the optical level on the Packet Node Colored Interface:

- Optical Power Transmit
- Optical Power Receive

[R-38] The Packet Node MUST support fault detection and alarming according to ITU-T G.709 [4]/ ITU-T G.798 [5].

[R-39] The Packet Node MUST support detecting payload type mismatch according to ITU-T G.798 [5].

[R-40] DWDM Alarm severity reporting SHOULD be supported per ITU-T G.7710 [10] (sections 7.1.3.1 “Severity assignment” and 7.2.2 “Severity assignment function - SEV) on the Packet Node Colored Interface.

Service Providers utilize Threshold Crossing Reports to notify the operator or NMS system when a pre-determined threshold has been crossed. The thresholds can be considered over any 15 min or 24 hour time period, in accordance with ITU-T G.7710/Y.1701.

[R-41] Threshold Crossing Alerts or Threshold Reports SHOULD be supported and set in the Packet Node according to G.874 [8] (Section 10.1.7) and ITU-T G.7710/Y.1701 [10] (Section 10.1.7). At a minimum, reports for the characteristics listed in [R-35] SHOULD be supported.

[R-42] The Packet Node SHOULD support pre-FEC BER monitoring at DWDM interfaces.

4.4 Provisioning the Optical Connection between the Packet Nodes

Provisioning requires a communication between a management device and one or many network elements to communicate properties of the optical connection, such as the wavelength used. Provisioning of the optical connection covers the setup of the lambda and other parameters such as destination address for the circuit and bandwidth.
It can be accomplished with one or a combination of the following methods:

- Via Command Line Interface
- Via NETCONF/YANG
- If a GMPLS-based control plane solution is used: via GMPLS RSVP-TE[3]
- If an SDN-based controller is used: via communication with controller(s) of the optical and packet domain

CLI configuration can be used to configure the optical connection on both the Packet Node and the DWDM Network Element if applicable. At the time a YANG model is defined, alternatively NETCONF/YANG may also be used to configure the Packet Node and DWDM Network Element.

If a GMPLS-based Control Plane solution is used: GMPLS RSVP-TE can be used to signal the applicable parameters between the Packet Nodes via the optical network

If an SDN solution is used, the SDN controller can coordinate the lambda configuration as well as other provisioning parameters on both the Packet Node and the DWDM Network Element.

Section 5 of TR-319 Part A provides operational requirements and interactions between packet and optical networks.

4.5 SDN Controller

Support of SDN is optional. When supported the following procedures will apply:

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[3] GMPLS itself is configured using one of the other methods on the above list.

Before being able to compute the optimal paths across the network, the SDN Controller needs to have a global view of the network topology. Many attributes such as link utilization, latency, bandwidth, and traffic statistics need to be collected for path computation.

The topology information can be collected using provisioning or routing protocols. Routing protocols provide a dynamic and real-time routing view of the network topology and are able to capture most network changes.

In a packet-optical network, the packet layer is the client of the optical network. Todays planning and optimization is done manually based on the data from each layer and using tools with limited scope. Coordinated, multilayer management and control allows for a globally optimized network and can be achieved using an SDN controller.
Once a path has been computed and ready to be provisioned to the network, the SDN controller will program the path and its associated features onto the target network devices.

SDN technology enables an integrated management system, as illustrated in Section 6 (Use of SDN Configuration and Management) of TR-319 [1].

[R-43] The Packet Node SHOULD support a standard interface to a SDN controller.

Note: It is assumed that the DWDM Network Element supports a similar interface.

5 Operational Aspects for Packet over Optical Networks

5.1 Interaction between Packet Client and DWDM/Optical Network

This section details several scenarios of interaction between the IP/Packet Node and the DWDM network, on the basis of having the DWDM interface physically or logically integrated into the Packet Node. Operational requirements and impacts for different levels of Management and Control Plane integration are addressed.

While the figures in the following sections show, for simplicity, a scenario with one unidirectional optical network connection, the common configuration in service provider networks is bidirectional.

5.1.1 Separated Network Management Systems

In the scenario shown in Figure 4 the DWDM optical interface is managed by the optical network management system. This means there must be a connection between the Network Management System (NMS or EMS) and the IP/packet switched network that contains the DWDM interface. This solution enables the management of the DWDM interfaces while keeping the status quo of a separated management of the optical and the IP/packet switched networks. There is no Control Plane involved in this scenario.

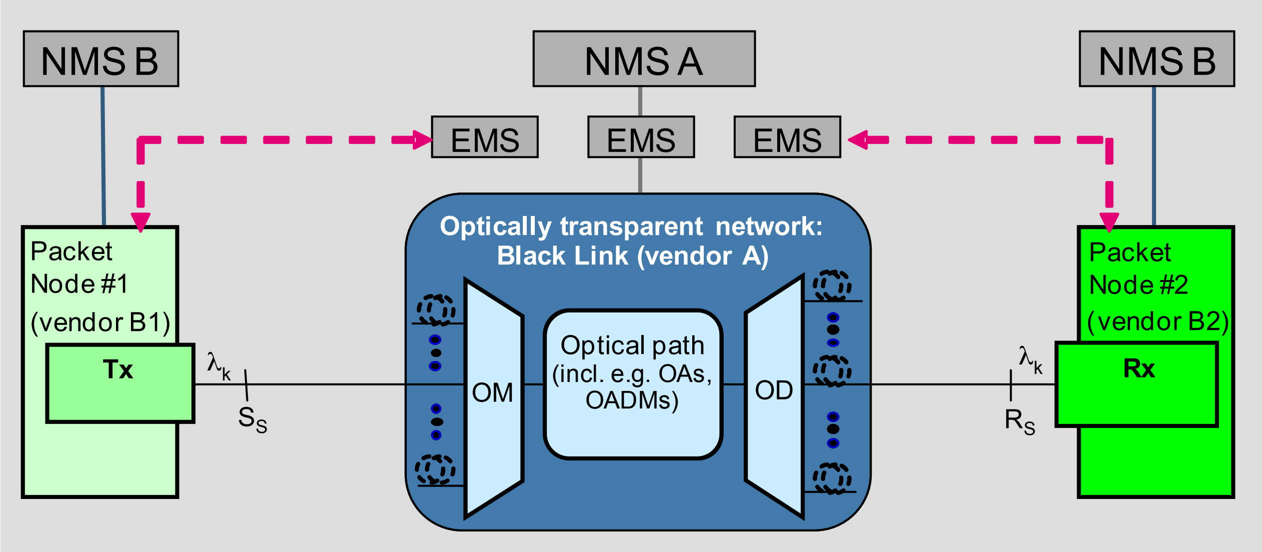

Figure 4: DWDM Interface Integration - Separated Network Management

Information about the interface status (alarms, failures, configuration details) must be mirrored (must be made available) within both network management systems. Information about L1 status will be available in the IP/Packet Node and can be used to trigger protection switching or resilience mechanisms, e.g. initiate a Fast Reroute (FRR) process of the IP network. NMS B has read-only access to L0 and L1 parameters of the DWDM interfaces, while NMS A has write access, i.e. administrative control of the DWDM interfaces.

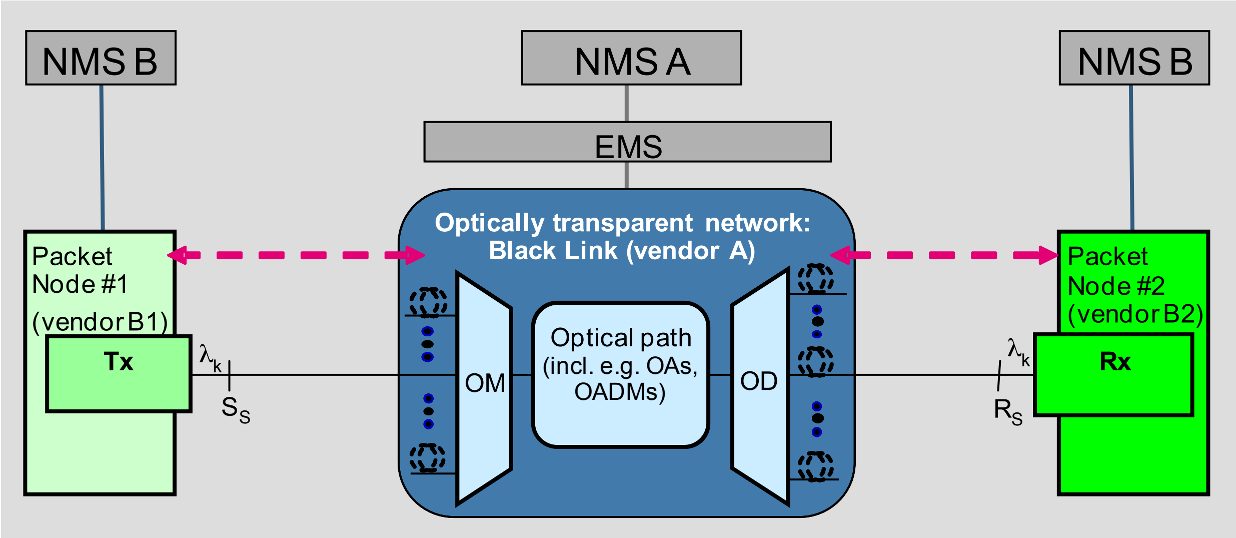

Figure 5: Virtually Integrated Network Management

Shown in Figure 5, is another scenario where a direct management channel is established between the Packet Node and the DWDM network to which it is connected. From the management perspective the DWDM interfaces appear as part of the optical network. NMS B has read-only access to L0 and L1 parameters at the DWDM interface, while NMS A has write access, i.e. administrative control of the DWDM interfaces. This scenario, providing virtually integrated network management, allows keeping separately operated and managed network domains.

Figure 4 and Figure 5 describe two different approaches to allow management of the optical interface by using one management system for the packet switched network domain and one for the optical domain. Management and configuration information must be exchanged between the two NMSs due to them being separate entities.

5.1.2 Separated Management Planes with Control Plane parameter sharing

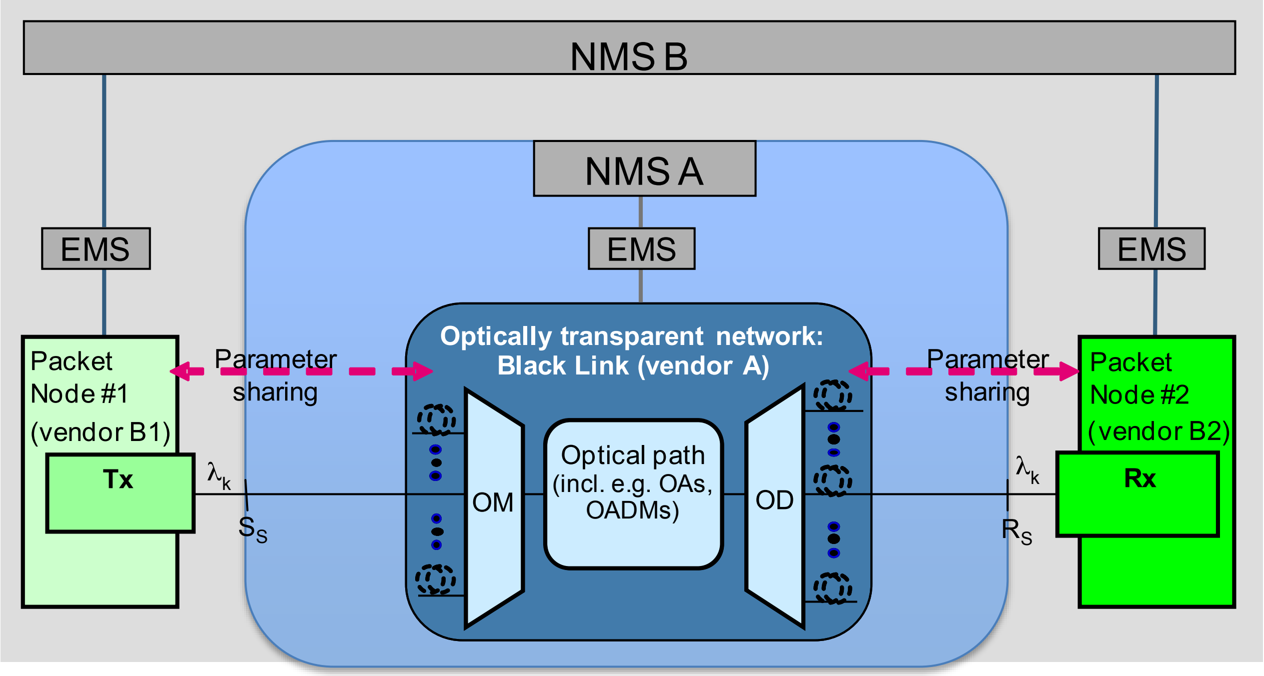

Figure 6: DWDM Interface Control Plane Integration - Separated Network Management

The separated management with parameter sharing approach is shown in Figure 6. A GMPLS Control Plane with LMP [20] enabled for link property exchange between the Packet Node and the DWDM network is envisaged. Utilizing this mechanism, characteristics of the interface S/R and their states are shared between the optical domain (in blue) and the client domain. As part of the information sharing, for example, threshold values that may have been set by the operator on one side of the link should be communicated. This allows either side to perform FCAPS locally and respect operational parameter ranges that originate from the remote side of the reference point. This way either side of the S/R interface can operate independently while keeping the information consistent across the interface and respecting design parameters operators like to supervise. Moreover the administrative state can be set independently by the relevant NMS but is shared among client and server domains. Hence both domains can be administered independently from each other while consistency of state is maintained for the link under control. From a NMS perspective, the DWDM interface is actively managed as part of the packet network while the optical drop interface is actively managed by the optical NMS. However the DWDM interface parameters and WDM drop port parameters are mirrored to the remote end of the reference point (i.e. between the optical line system and the transponder device). Hence both sides have a shared knowledge about the remote parameters of the access link and their options. This way both NMS can perform FCAPS on their locally controlled devices independent from each other while the Control Plane keeps the remote domain updated about parameter changes. NMS B has administrative control to L0 and L1 parameters of the DWDM interface, while the NMS A has shared read access. This scenario allows keeping separately operated and managed network domains.

5.1.3 Common Network Management

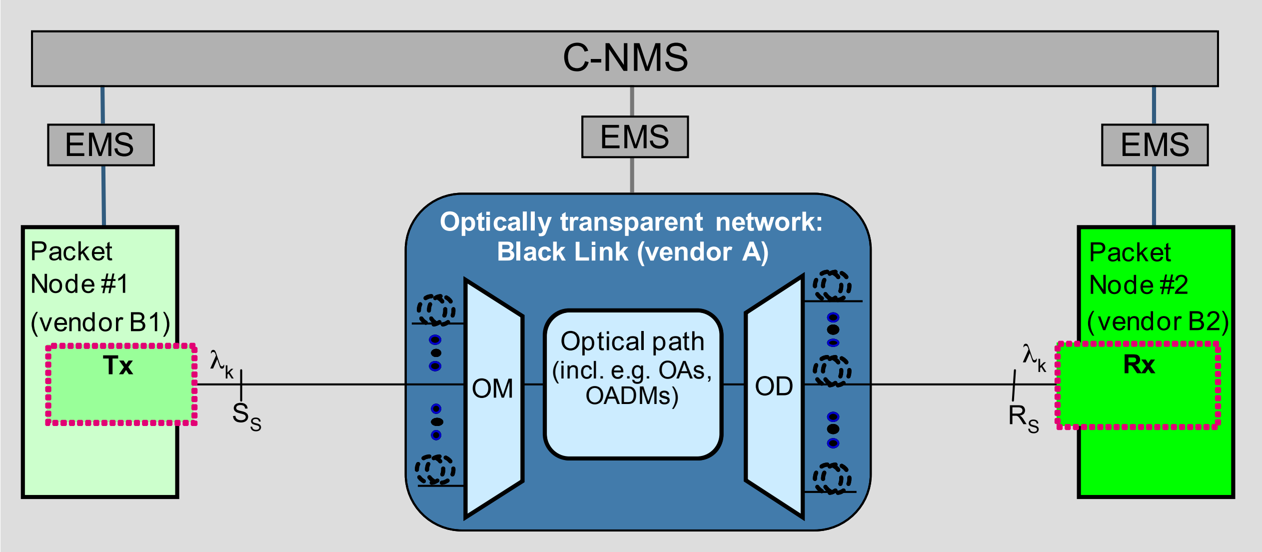

Figure 7: Common Network Management

A higher level of integration can be achieved with a Common-Network Management System (C-NMS, Figure 7). A single, converged operation and management provides a single point of network operation.

Management Plane functionality can be reduced in a second step by shifting some of the Management Plane tasks towards a GMPLS Control Plane, as described in section 5.1.4.

5.1.4 Migration to Fully Integrated Management and Control Planes

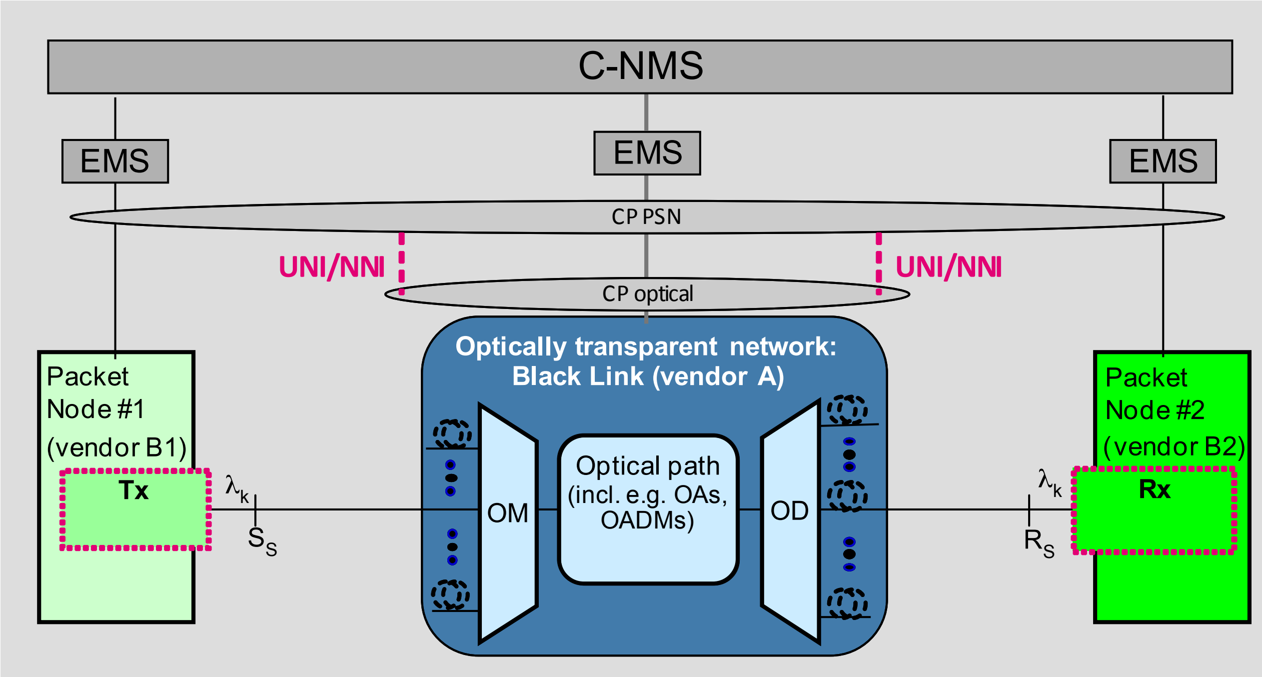

Figure 8: Fully integrated approach of common Management and Control Plane

Figure 8 shows one example of an overlay model supported by a common Management Plane and interworking between the Control Planes. The optical Control Plane models (e.g. based on GMPLS) must support mechanisms for information exchange between the IP/packet and the DWDM network infrastructure. The degree of integration impacts the efficiency of information exchange in relation to the network operation, i.e. OPEX.

Annex A Support of 100 Gbit/s Interfaces

[NORMATIVE]

The Physically Integrated Model addresses full integration by moving the Colored Interface physically into the Packet Node. The support of 100 Gbit/s interfaces is optional. This Annex satisfies the 100Gbit/s business requirement. When this Annex is supported, the following requirements in this section apply.

Section 4 specifies the nodal requirements for packet and DWDM/optical integration. The sections below specify interface requirements for 100 Gbit/s.

A.1 Interface Requirements

[R-44] The Packet Node MUST support standardized frame structure for OTU4 according to ITU-T G.709 section 11 [4].

[R-45] The Packet Node MUST support OTU4V framing, according to ITU-T G.709 [4].

[R-46] The Packet Node MUST support an enhanced FEC (EFEC) for 100G.
Note: Until such time as an enhance FEC is standardized, two devices must use the same enhanced FEC to enable interoperability.

A.2 Payload Mapping

[R-47] The Packet Node MUST support mapping of 100 G Ethernet into OPU4 by GMP+TTT procedures as per clause 17.7.5/ITU-T G.709 [4].

A.3 Transmitter and Receiver Characteristics

[R-48] The Packet Node MUST be able to transmit and receive optical wavelengths conforming to the DWDM frequency grid as per ITU-T G.694.1 [2].

[R-49] The Packet Node MUST support advanced modulation format with coherent detection for 100G.
Note: Until such time as an advanced modulation format with coherent detection is standardized, two devices must use the same advanced modulation format with coherent detection to enable interoperability.

[R-50] The Packet Node MUST support a standardized: line framing, encoding scheme, constellation mapping, in particular with respect to signals with a coherent modulation format.

A.4 Transmitter-Side (Ss)

[R-51] For coherent DWDM signals, the Packet Node Management Plane MUST support turning the Colored Interface transmitter off, while keeping the receiver on.

A.5 Receiver-Side (Rs)

[R-52] The Management Plane MUST support reporting the OSNR on the Colored Interface.

End of Broadband Forum Technical Report TR-319 Part A