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A framework for Management and Control of DWDM optical interface
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Abstract

To ensure an efficient data transport, meeting the requirements requested by today's IP-services the control and management of DWDM interfaces is a precondition for enhanced multilayer networking and for an further automation of network provisioning and operation. This document describes use cases and requirements for the control and management of optical interfaces parameters according to different types of single channel DWDM interfaces. The focus is on automating the network provisioning process irrespective on how it is triggered i.e. by EMS, NMS or GMPLS. This document covers management as well as control plane considerations in different management cases of a single channel DWDM interface The purpose is to identify the necessary information elements and processes to be used by control or management systems for further processing.

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1. Introduction

The usage of the Colored interfaces in the Client Nodes connected to a DWDM Network (which include ROADMs and optical amplifiers) adds further networking option for operators opening to new scenarios and requiring more control/management plane integration.

Carriers deploy their networks today as a combination of transport and packet infrastructures to ensure high availability and flexible data transport. Both network technologies are usually managed by different operational units using different management concepts. This is the status quo in many carrier networks today. In the case of a black link deployment, where the optical transport interface moves into the client device (e.g. , router), it is necessary to coordinate the management of the optical interface at the client domain with the optical transport domain. There are different levels of coordination, which are specified in this framework.

The objective of this document is to provide a framework that describes the solution space for the control and management of single channel interfaces and give use cases on how to manage the solutions. In particular, it examines topological elements and related network management measures. From an architectural point of view, the network can be considered as a black link, that is a set of pre-configured/qualified unidirectional, single-fiber, network connections between the G.698.2 reference points S and R. The optical transport network is managed and controlled in order to provide Optical Connections at the intended centre frequencies and the optical interfaces are managed and controlled to generate signals of the intended centre frequencies and further parameters as specified in ITU-T Recommendations G.698.2 and G.798. The Management or Control planes of the Client and DWDM network must know the parameters of the Interfaces to properly set the optical link.

Furthermore, support for Fast Fault Detection can benefit from the solution proposed.

Optical Routing and Wavelength assignment based on WSON is out of scope although can benefit of the way the optical parameters are exchanged between the Client and the DWDM Network.

Additionally, the wavelength ordering process and the process how to determine the demand for a new wavelength from A to Z is out of scope.

Note that the Control and Management Planes are two separate entities that are handling the same information in different ways. This

document covers management as well as control plane considerations in different management cases of single channel DWDM interfaces.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119].

2. Terminology and Definitions

Current generation WDM networks are single vendor networks where the optical line system and the transponders are tightly integrated. The DWDM interfaces migration from the Transponders to the Client interfaces changes this scenario, by introducing a standardized interface at the level of OCh between the Client DWDM interface and the DWDM network.

Black Link: The Black Link [ITU.G698.2] allows supporting an optical transmitter/receiver pair of a single vendor or from different vendors to provide a single optical channel interface and transport it over an optical network composed of amplifiers, filters, add-drop multiplexers which may be from a different vendor. Therefore the standard defines the ingress and egress parameters for the optical interfaces at the reference points Ss and Rs.

Single Channel DWDM Interface: The single channel interfaces to DWDM systems defined in G.698.2, which currently include the following features: channel frequency spacing: 50 GHz and wider (defined in [ITU-T G.694.1]); bit rate of single channel: Up to 10 Gbit/s. Future revisions are expected to include application codes for bit rates up to 40 Gb/s.

Forward error correction (FEC): FEC is a way of improving the performance of high-capacity optical transmission systems. Employing FEC in optical transmission systems yields system designs that can accept relatively large BER (much more than 10⁻¹²) in the optical transmission line (before decoding).

Administrative domain [G.805]: For the purposes of this Recommendation an administrative domain represents the extent of resources which belong to a single player such as a network operator, a service provider or an end-user. Administrative domains of different players do not overlap amongst themselves.

Intra-domain interface (IaDI) [G.872]: A physical interface within an administrative domain.

Inter-domain interface (IrDI) [G.872]: A physical interface that represents the boundary between two administrative domains.

Management Plane [G.8081]: The management plane performs management functions for the transport plane, the control plane and the system as a whole. It also provides coordination between all the planes. The following management functional areas are performed in the management plane: performance management; fault management; configuration management; accounting management and security management.

Control Plane [G.8081]: The control plane performs neighbour discovery, call control and connection control functions. Through signalling, the control plane sets up and releases connections, and may restore a connection in case of a failure. The control plane also performs other functions in support of call and connection control, such as neighbour discovery and routing information dissemination.

Transponder: A Transponder is a network element that performs O/E/O (Optical /Electrical/Optical) conversion. In this document it is referred only transponders with 3R (rather than 2R or 1R regeneration) as defined in [ITU.G.872].

Client DWDM interface: A Transceiver element that performs E/O (Electrical/Optical) conversion. In this document it is referred as the DWDM side of a transponder as defined in [ITU.G.872].

3. Solution Space Client DWDM interface

The management of optical interfaces using the Black Link approach deals with aspects related to the management of single-channel optical interface parameters of physical point-to-point and ring DWDM applications on single-mode optical fibres.

The solution allows the direct connection of a wide variety of equipments using a DWDM link, for example:

1. A digital cross-connect with multiple optical interfaces, supplied by a different vendor from the line system
2. Multiple optical client devices, each from a different vendor, supplying one channel each
3. A combination of the above

Table 1 provides a list of management regarding the configuration of optical parameters.

Task	Domain	a	b	c	d
determination of centre frequency	optical	R	R	R	R
configuration of centre frequency at optical IF	client	NR	NR	R	R
path computation of wavelength	optical	NR	NR	R	R
routing of wavelength	optical	NR	NR	R	R
wavelength setup across optical network	optical	?	?	R	R
detection of wavelength fault	client	R	R	R	R
fault isolation, identification of root failure	optical	NR	R	R	R
repair actions within optical network	optical	R	R	R	R
protection switching of wavelength	optical	NR	NR	R	R
restoration of wavelength	optical	NR	NR	R	R

Note: R = relevant, NR = not relevant

Table 1: List of tasks related to Client - Network interconnection management

Furthermore the following deployment cases will be considered:

- a. Passive WDM
- b. P2P WDM systems
- c. WDM systems with OADMs
- d. Transparent optical networks supporting specific IPoWDM functions, nterfaces, protocols etc.

Case a) is added for illustration only, since passive WDM is specified in ITU-T Recommendations G.695 and G.698.1.

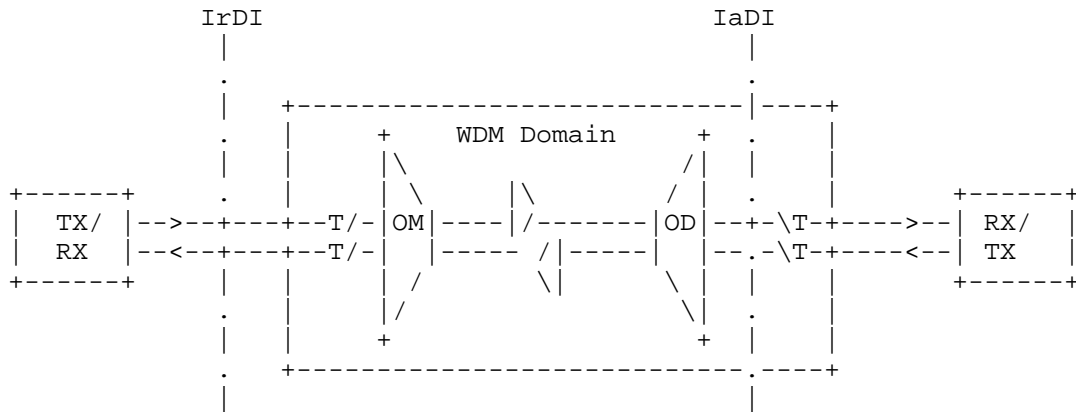
Case b) and case c) are motivated by the usage of legacy equipment using the traditional connection as described in Figure 1 combined with the BL approach.

3.1. Comparison of approaches for transverse compatibility

3.1.1. Multivendor DWDM line system with transponders

As illustrated in Figure 1, for this approach interoperability is achieved via the use of optical transponders providing OEO (allowing conversion to appropriate parameters). The optical interfaces

labelled "single channel non-DWDM interfaces from other vendor(s)" and "Single channel non DWDM interfaces to/from other vendor(s)" can then be any short reach standardized optical interface that both vendors support, such as those found in [ITU-T G.957] [ITU-T G.691], [ITU-T G.693], [ITU-T G.959.1], etc.



TX/RX = Single channel non-DWDM interfaces
T/ = Transponder
OM = Optical Mux
OD = Optical Demux

Figure 1: Inter and Intra-Domain Interface Identification

In the scenario of Figure 1 the administrative domain is defined by the Interdomain Interface (IrDI). This interface terminates the DWDM domain. The line side is characterized by the IaDI. This interface specifies the internal parameter set of the optical administrative domain. In the case of Client DWDM interface deployment this interface moves into the client devices and extends the optical and administrative domain towards the client node. ITU-T G.698.2 specifies the parameter set for a certain set of applications.

This document elaborates only the IaDI Interface as specified in ITU-T G.698.2 as transversely compatible and multi-vendor interface within one administrative domain controlled by the network operator. This administrative domain can contain several vendor domains (vendor A for the DWDM sub-network, and vendors B1 and B2 at the transmitter and receiver terminal side).

3.1.2. Black Link Deployments

In case of a Black Link deployment as shown in Figure 2, through the use of the single channel DWDM interfaces defined in [ITU.G698.2], multi-vendor interconnection can also be achieved while removing the need for one s hort reach transmitter and receiver pair per channel (eliminating the transponders).

Network Management System (NMS), allowing consistent end-to-end management of the connection.

To facilitate consistent end-to-end network management, the north bound management interface from the EMS to the NMS should be consistent (from a management information point of view) with the standard protocol-neutral (or protocol-specific) information model used in the EMS south bound management interface to its subtending NEs (TX and/or RX). The [Interface-MIB] defines such a protocol-specific information using SNMP/SMI, Yang models and LMP TLV to support the direct exchange of information between the Client and the Network control planes.

4. Solutions for managing and controlling the optical interface

Operation and management of WDM systems is traditionally seen as a homogenous group of tasks that could be carried out best when a single management system or an umbrella management system is used. Currently each WDM vendor provides an Element Management System (EMS) that also administers the wavelengths.

Therefore from the operational point of view there are the following approaches will be considered to manage and operate optical interfaces.

<vspace>:

1. Separate operation and management of client device and the transport network
 - a. Direct link between the client device and the management system of the optical network (e.g. EMS, NMS)
 - b. Indirect link to the management system of the optical network using a protocol between the client device and the directly connected WDM system node to exchange management information with the optical domain
2. Common operation and management of client device and the Transport network

The first option keeps the status quo in large carrier networks as mentioned above. In that case it must be ensured that the full FCAPS Management (Fault, Configuration, Accounting, Performance and Security) capabilities are supported. This means from the management staff point of view nothing changes. The transceiver/receiver optical interface will be part of the optical management domain and will be managed from the transport management staff.

The second solution addresses the case where underlying WDM transport network is mainly used to interconnect a homogeneous set of client nodes (e.g. IP routers or digital crossconnects). Since the service creation and restoration could be done by to higher layers (e.g. IP), this may lead to more efficient network operation and a higher level of integration.

4.1. Separate Operation and Management Approaches

4.1.1. Direct connection to the management system

It must be ensured that the optical network interface can be managed in a standardised way to enable interoperable solutions between different optical interface vendors and vendors of the optical network management application. RFC 3591 [RFC3591] defines managed objects for the optical interface type but needs further extension to cover the optical parameters required by this framework document. Therefore an extension to this MIB for the optical interface has been drafted in [Black-Link-MIB]. In that case SNMP is used to exchange data between the client device and the management system of the WDM domain. Yang models are as well needed to enable and SDN controller to easily read/provision the interfaces parameters.

Note that a software update of the optical interface components of the client nodes must not lead obligatory to an update of the software of the EMS and vice versa.

4.1.2. Direct connection to the DWDM management system

The alternative as shown in Figure 4 can be used in cases where a more integrated relationship between transport node (e.g. OM or OD) and client device is aspired. In that case a combination of control plane features and manual management will be used.

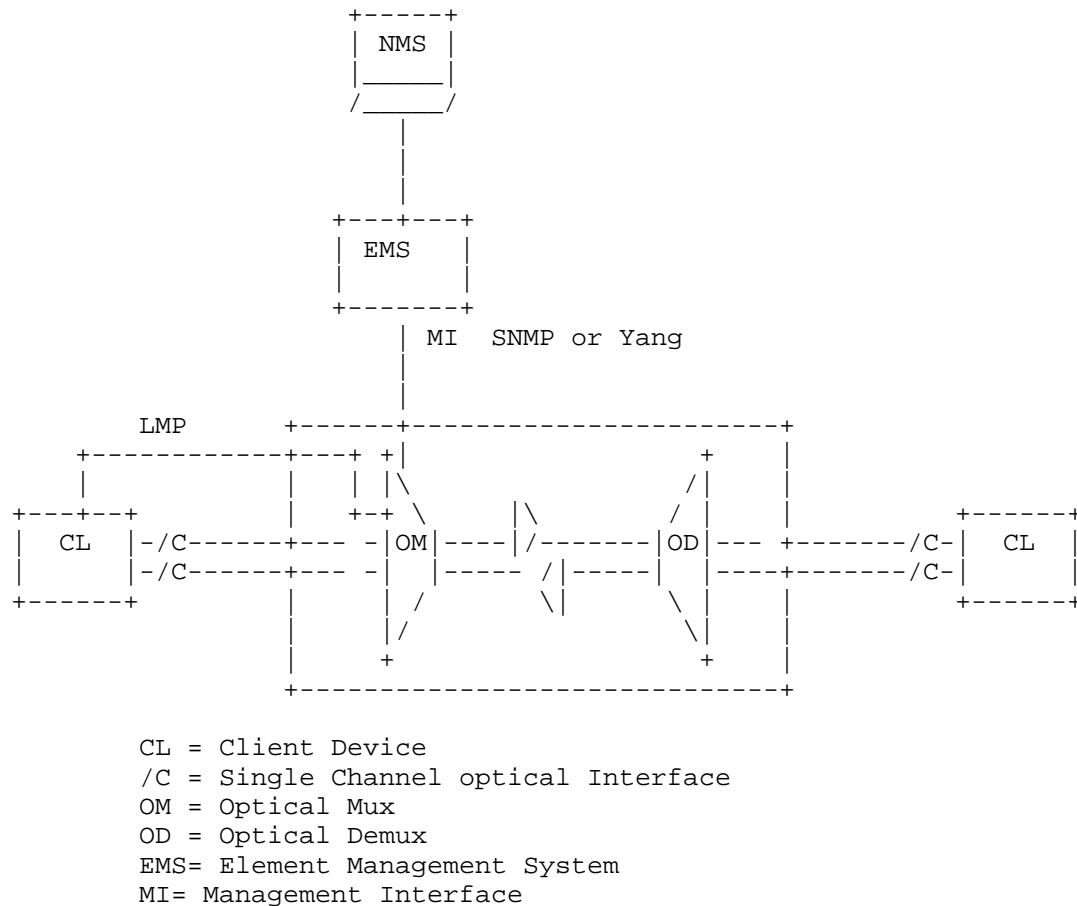


Figure 4: Direct connection between peer node and first optical network node

For information exchange between the client node and the direct connected node of the optical transport network LMP as specified in RFC 4209 [RFC4209] can (should) be used. This extension of LMP may be used between a peer node and an adjacent optical network node as depicted in Figure 4.

The LMP based on RFC 4209 does not yet support the transmission of configuration data (information). This functionality has to be added to the existing extensions of the protocol. The use of LMP-WDM assumes that some form of a control channel exists between the client node and the WDM equipment. This may be a dedicated lambda, an Ethernet Link, or other signaling communication channel (SCC or IPCC).

4.2. Control Plane Considerations

The concept of black link equally applies to management and control plane mechanisms. The general GMPLS control Plane for wavelength switched optical networks is work under definition in the scope of WSON. One important aspect of the BL is the fact that it includes the wavelength that is supported by the given link. Thus a BL can logically be considered as a fiber that is transparent only for a single wavelength. In other words, the wavelength becomes a characteristic of the link itself. Nevertheless the procedure to light up the fiber may vary depending on the BL implementation. Since the implementation of the BL itself is unknown a priori, different sequences to light up wavelength need to be considered:

1. Transponders first, transponder tuning: The transmitter is switched on and the BL is immediately transparent to its wavelength. This requires the transmitter to carefully tune power and frequency not overload the line system or to create transients.
2. Transponder first, OLS tuning: The transmitter is switched on first and can immediately go to the max power allowed since the OLS performs the power tuning. This leads to an intermediate state where the receiver does not receive a valid signal while the transmitter is sending out one. Alarm suppression mechanisms shall be employed to overcome that condition.
3. OLS first, Transponder tuning: At first the OLS is tuned to be transparent for a given wavelength, then transponders need to be tuned up. Since the OLS in general requires the presence of a wavelength to fine-tune its internal facilities there may be a period of time where a valid signal is transmitted but the receiver is unable to detect it. This equally needs to be covered by alarm suppression mechanisms.
4. OLS first, OLS tuning: The OLS is programmed to be transparent for a given Wavelength, then the transponders need to be switched on and further power tuning takes place. The sequencing of enabling the link needs to be covered as well.

The preferred way to address these in a Control Plane enabled network is neighbour discovery including exchange of link characteristics and link property correlation. The general mechanisms are covered in RFC4209 [LMP-WDM] and RFC 4204[LMP] which provides the necessary protocol framework to exchange those characteristics between client and black link. LMP-WDM is not intended for exchanging routing or signalling information but covers:

1. Control channel management
2. Link property correlation
3. Link verification
4. Fault Manangement

Extensions to LMP/LMP-WDM covering the code points of the BL definition are needed. Additionally when client and server side are managed by different operational entities, Link state exchange is required to align the management systems.

4.2.1. Considerations using GMPLS UNI

The deployment of G.698.2 optical interfaces is leading to some functional changes related to the control plane models and has therefore some impact on the existing interfaces especially in the case of an overlay model where the edge node requests resources from the core node and the edges node do not participate in the routing protocol instance that runs among the core nodes. RFC 4208 [RFC4208] defines the GMPLS UNI that will be used between edge and core node. In case of a black link deployment additional functionalities are needed to setup a connection.

It is necessary to differentiate between topology/signalling information and configuration parameters that are needed to setup a wavelength path. RSVP-TE could be used for the signalling and the reservation of the wavelength path. But there are additional information needed before RSVP-TE can start the signalling process. There are three possibilities to proceed:

- a. Using RSVP-TE only for the signalling and LMP as described above to exchange information to configure the optical interface within the edge node or
- b. RSVP-TE will be used to transport additional information

- c. Leaking IGP information instead of exchanging this information needed from the optical network to the edge node (overlay will be transformed to a border-peer model)

Furthermore following issues should be addressed:

- a) The Communication between peering edge nodes using an out of band control channel. The two nodes have to exchange their optical capabilities. An extended version of LMP is needed to exchange FEC Modulation scheme, etc. that must be the same. It would be helpful to define some common profiles that will be supported. Only if the profiles match with both interface capabilities it is possible start signalling.

- b) Due to the bidirectional wavelength path that must be setup it is obligatory that the upstream edge node inserts a wavelength value into the path message for the wavelength path towards the upstream node itself. But in the case of an overlay model the client device may not have full information which wavelength must/should be selected and this information must be exchanged between the edge and the core node.

5. Operational aspects using IUT-T G.698.2 specified single channel DWDM interfaces

A Comparison of the Black Link with the traditional operation scenarios provides an insight of similarities and distinctions in operation and management. The following four use cases provide an overview about operation and maintenance processes.

5.1. Bringing into service

It is necessary to differentiate between two operational issues for setting up a light path (a DWDM connection is specific in having defined maximum impairments) within an operational network. The first step is the preparation of the connection if no optical signal is applied. Therefore it is necessary to define the path of the connection.

The second step is to setup the connection between the Client DWDM interface and the ROADM port. This is done using the NMS of the optical transport network. From the operation point of view the task is similar in a Black Link scenario and in a traditional WDM environment. The Black Link connection is measured by using BER tester which use optical interfaces according to G.698.2. These measurements are carried out in accordance with ITU-T Recommendation M.xxxx. When needed further Black Link connections for resilience are brought into service in the same way.

In addition some other parameters like the Transmit Optical Power, the Received Optical Power, the Frequency, etc. must be considered.

If the optical interface moves into a client device some of changes from the operational point of view have to be considered. The centre frequency of the Optical Channel was determined by the setup process. The optical interfaces at both terminals are set to the centre frequency before interconnected with the dedicated ports of the WDM network. Optical monitoring is activated in the WDM network after the terminals are interconnected with the dedicated ports in order to monitor the status of the connection. The monitor functions of the optical interfaces at the terminals are also activated in order to monitor the end to end connection.

Furthermore it should be possible to automate this last step. After connecting the client device towards the first control plane managed transport node a control connection may e.g. be automatically established using LMP to exchange configuration information.

If tunable interfaces are used in the scenario it would be possible to define a series of backup wavelength routes for restoration that could be tested and stored in backup profile. In fault cases this wavelength routes can be used to recover the service.

5.2. LMP Use Cases

The use cases described below are assuming that power monitoring functions are available in the ingress and egress network element of the DWDM network, respectively. By performing link property correlation it would be beneficial to include the current transmit power value at reference point Ss and the current received power value at reference point Rs. For example if the Client transmitter power (OXC1) has a value of 0dBm and the ROADM interface measured power (at OLS1) is -6dBm the fiber patch cord connecting the two nodes may be pinched or the connectors are dirty. More, the interface characteristics can be used by the OLS network Control Plane in order to check the Optical Channels feasibility. Finally the OXC1 transceivers parameters (Application Code) can be shared with OXC2 using the LMP protocol to verify the Transceivers compatibility. The actual route selection of a specific wavelength within the allowed set is outside the scope of LMP. In GMPLS, the parameter selection (e.g. central frequency) is performed by RSVP-TE.

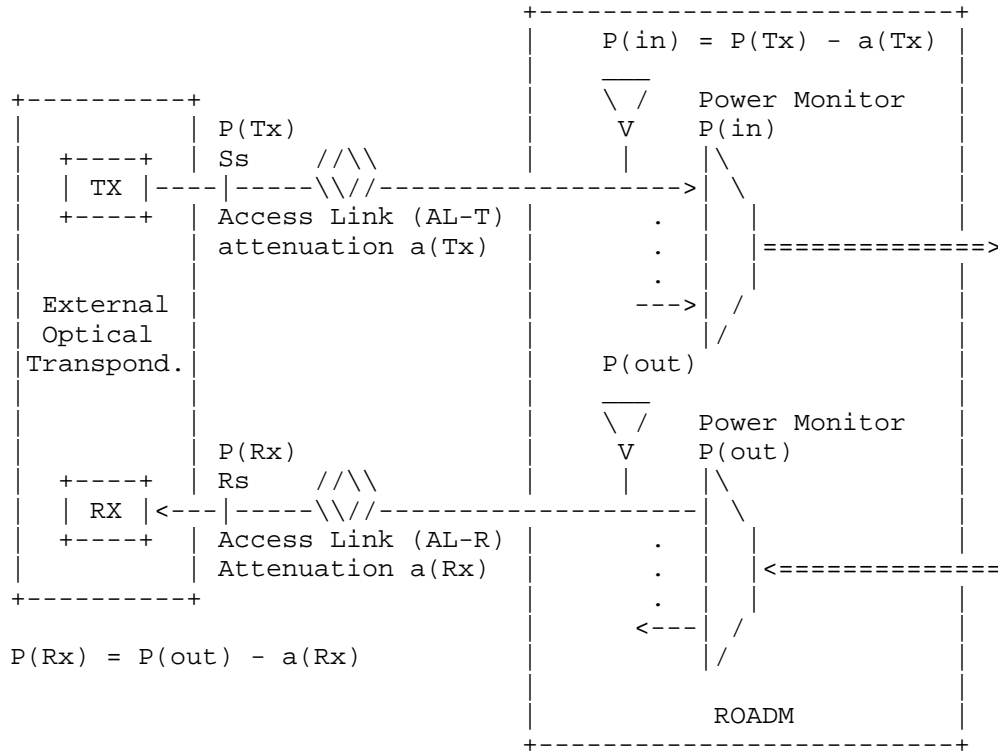
G.698.2 defines a single channel optical interface for DWDM systems that allows interconnecting network-external optical transponders across a DWDM network. The optical transponders are considered to be external to the DWDM network. This so-called 'black link' approach illustrated in Figure 5-1 of G.698.2 and a copy of this figure is

provided below. The single channel fiber link between the Ss/Rs reference points and the ingress/egress port of the network element on the domain boundary of the DWDM network (DWDM border NE) is called access link in this contribution. Based on the definition in G.698.2 it is considered to be part of the DWDM network. The access link typically is realized as a passive fiber link that has a specific optical attenuation (insertion loss). As the access link is an integral part of the DWDM network, it is desirable to monitor its attenuation. Therefore, it is useful to detect an increase of the access link attenuation, for example, when the access link fiber has been disconnected and reconnected (maintenance) and a bad patch panel connection (connector) resulted in a significantly higher access link attenuation (loss of signal in the extreme case of an open connector or a fiber cut). In the following section, two use cases are presented and discussed:

- 1) pure access link monitoring
- 2) access link monitoring with a power control loop

These use cases require a power monitor as described in G.697 (see section 6.1.2), that is capable to measure the optical power of the incoming or outgoing single channel signal. The use case where a power control loop is in place could even be used to compensate an increased attenuation as long as the optical transmitter can still be operated within its output power range defined by its application code.

Figure 5 Access Link Power Monitoring



- For AL-T monitoring: $P(Tx)$ and $a(Tx)$ must be known
- For AL-R monitoring: $P(Rx)$ and $a(Rx)$ must be known

An alarm shall be raised if $P(in)$ or $P(Rx)$ drops below a configured threshold (t [dB]):

- $P(in) < P(Tx) - a(Tx) - t$ (Tx direction)
- $P(Rx) < P(out) - a(Rx) - t$ (Rx direction)
- $a(Tx) = | a(Rx)$

Figure 5: Extended LMP Model

Pure Access Link (AL) Monitoring Use Case

Figure 4 illustrates the access link monitoring use case and the different physical properties involved that are defined below:

- S_s, R_s : Single Channel reference points
- $P(Tx)$: current optical output power of transmitter Tx
- $a(Tx)$: access link attenuation in Tx direction (external transponder point of view)
- $P(in)$: measured current optical input power at the input port of border DWDM NE
- t : user defined threshold (tolerance)
- $P(out)$: measured current optical output power at the output port of border DWDM NE
- $a(Rx)$: access link attenuation in Rx direction (external transponder point of view)
- $P(Rx)$: current optical input power of receiver Rx

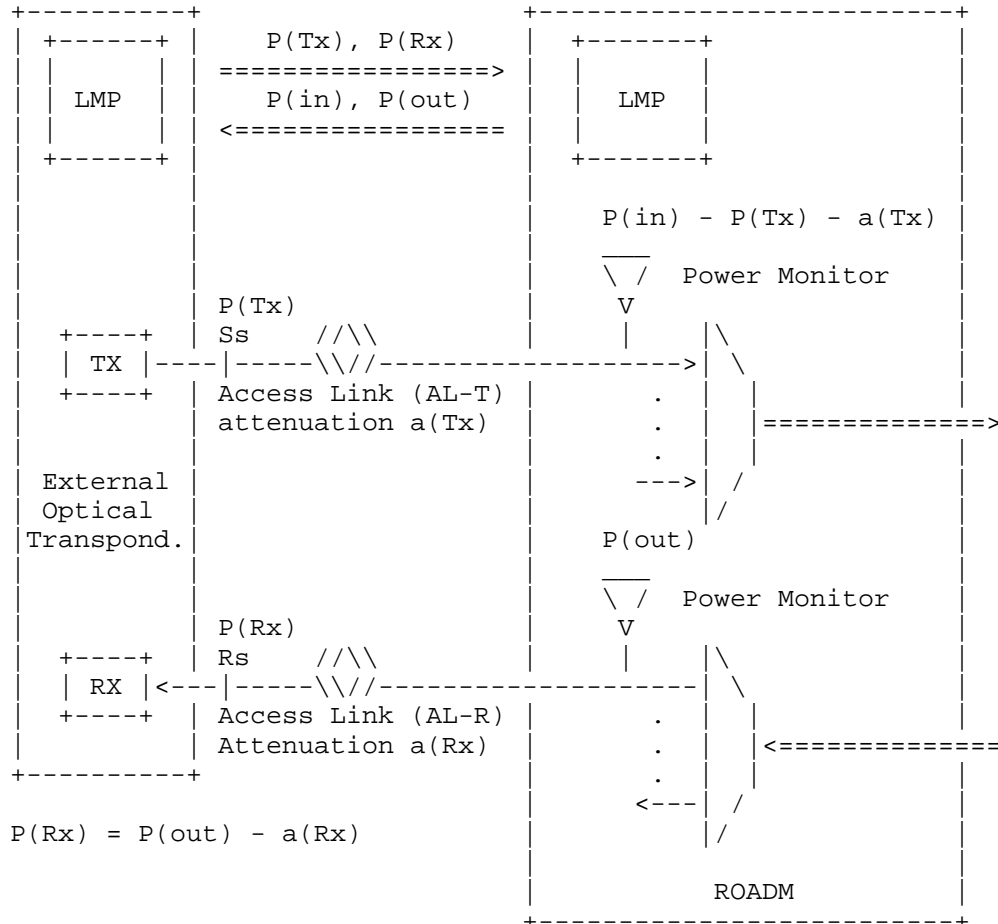
Description:

- The access link attenuation in both directions ($a(Tx)$, $a(Rx)$) is known or can be determined as part of the commissioning process. Typically, both values are the same.
- A threshold value t has been configured by the operator. This should also be done during commissioning.
- A control plane protocol (e.g. this draft) is in place that allows to periodically send the optical power values $P(Tx)$ and $P(Rx)$ to the control plane protocol instance on the DWDM border NE. This is illustrated in Figure 3.
- The DWDM border NE is capable to periodically measure the optical power P_{in} and P_{out} as defined in G.697 by power monitoring points depicted as yellow triangles in the figures below.

AL monitoring process:

- Tx direction: the measured optical input power P_{in} is compared with the expected optical input power $P(Tx) - a(Tx)$. If the measured optical input power P_{in} drops below the value $(P(Tx) - a(Tx) - t)$ a low power alarm shall be raised indicating that the access link attenuation has exceeded $a(Tx) + t$.
- Rx direction: the measured optical input power $P(Rx)$ is compared with the expected optical input power $P(out) - a(Rx)$. If the measured optical input power $P(Rx)$ drops below the value $(P(out) - a(Rx) - t)$ a low power alarm shall be raised indicating that the access link attenuation has exceeded $a(Rx) + t$.
- to avoid toggling errors, the low power alarm threshold shall be lower than the alarm clear threshold.

Figure 6 Use case 1: Access Link power monitoring



- For AL-T monitoring: $P(Tx)$ and $a(Tx)$ must be known
 - For AL-R monitoring: $P(Rx)$ and $a(Rx)$ must be known
- An alarm shall be raised if $P(in)$ or $P(Rx)$ drops below a configured threshold (t [dB]):
- $P(in) < P(Tx) - a(Tx) - t$ (Tx direction)
 - $P(Rx) < P(out) - a(Rx) - t$ (Rx direction)
 - $a(Tx) = a(Rx)$

Figure 6: Extended LMP Model

Power Control Loop Use Case

This use case is based on the access link monitoring use case as described above. In addition, the border NE is running a power control application that is capable to control the optical output power of the single channel tributary signal at the output port of the border DWDM NE (towards the external receiver Rx) and the optical output power of the single channel tributary signal at the external transmitter Tx within their known operating range. The time scale of this control loop is typically relatively slow (e.g. some 10s or minutes) because the access link attenuation is not expected to vary much over time (the attenuation only changes when re-cabling occurs).

From a data plane perspective, this use case does not require additional data plane extensions. It does only require a protocol extension in the control plane (e.g. this LMP draft) that allows the power control application residing in the DWDM border NE to modify the optical output power of the DWDM domain-external transmitter Tx within the range of the currently used application code. Figure 5 below illustrates this usecase utilizing the LMP protocol with extensions defined in this draft.

Figure 7 Use case 2: Power Control Loop

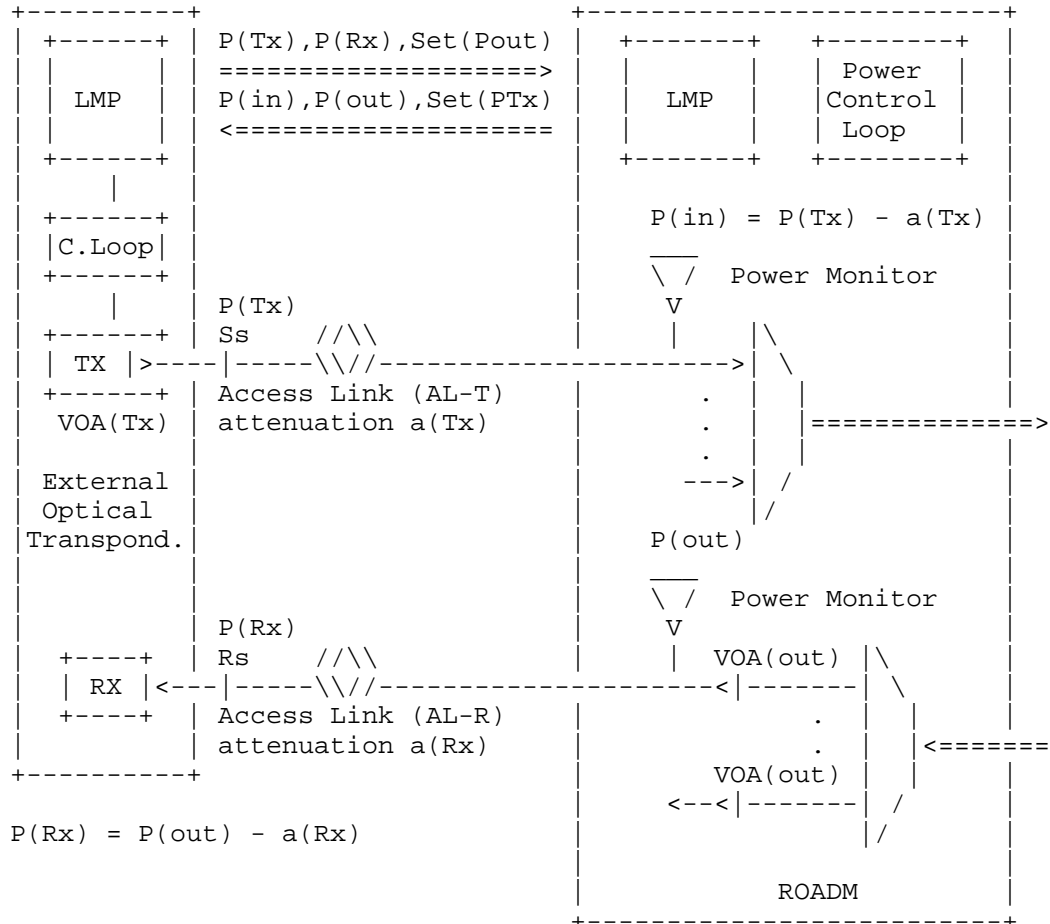


Figure 7: Extended LMP Model

- The Power Control Loops in Transponder and ROADM controls the Variable Optical Attenuators (VOA) to adjust the proper power in base of the ROADM and Receiver characteristics and the Access Link attenuation

6. Acknowledgements

The author would like to thank Ulrich Drafz for the very good teamwork during the last years and the initial thoughts related to the packet optical integration. Furthermore the author would like to thank all people involved within Deutsche Telekom for the support and fruitful discussions.

7. IANA Considerations

This memo includes no request to IANA.

8. Security Considerations

The architecture and solution space in scope of this framework imposes no additional requirements to the security models already defined in RFC5920 for packet/optical networks using GMPLS, covering also Control Plane and Management interfaces. Respective security mechanisms of the components and protocols, e.g. LMP security models, can be applied unchanged.

As this framework is focusing on the single operator use case, the security concerns can be relaxed to a subset compared to a setup where information is exchanged between external parties and over external interfaces.

Concerning the access control to Management interfaces, security issues can be generally addressed by authentication techniques providing origin verification, integrity and confidentiality. Additionally, access to Management interfaces can be physically or logically isolated, by configuring them to be only accessible out-of-band, through a system that is physically or logically separated from the rest of the network infrastructure. In case where management interfaces are accessible in-band at the client device or within the optical transport network domain, filtering or firewalling techniques can be used to restrict unauthorized in-band traffic. Authentication techniques may be additionally used in all cases.

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