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A YANG Data Model for Optical Impairment-aware Topology
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Abstract

In order to provision an optical connection through optical networks, a combination of path continuity, resource availability, and impairment constraints must be met to determine viable and optimal paths through the network. The determination of appropriate paths is known as Impairment-Aware Routing and Wavelength Assignment (IA-RWA) for a Wavelength Switched Optical Network (WSON), while it is known as Impairment-Aware Routing and Spectrum Assignment (IA-RSA) for a Spectrum Switched Optical Network (SSON).

This document provides a YANG data model for the impairment-aware Traffic Engineering topology (TE topology) in optical networks. It augments the technology agnostic YANG Data Model for TE topologies. The topology YANG model provides read-only topology data including optical impairments that can be used for example by a Path Computation Engine (PCE) for calculating an optically feasible path for a new connection before it is established through an optical network.

Status of This Memo

This Internet-Draft will expire on 31 August 2026.

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1. Introduction

In order to provision an optical connection (an optical path) through wavelength switched optical networks (WSONs) as defined in [RFC9094] or spectrum switched optical networks (SSONs), a combination of path continuity, resource availability, and impairment constraints must be met to determine viable and optimal paths through the network. The determination of appropriate paths is known as Impairment-Aware Routing and Wavelength Assignment (IA-RWA) [RFC6566] for WSON, while it is known as IA-Routing and Spectrum Assigment (IA-RSA) for SSON.

An introduction to optical impairments and their impact on optical signals (degradation) is provided in [RFC6566].

This document provides a YANG data model for the impairment-aware Traffic Engineering (TE) topology in WSONs and SSONs. The YANG model described in this document is a WSON/SSON technology-specific YANG model based on the information model developed in [RFC7446] and the two encoding documents [RFC7581] and [RFC7579] that developed protocol independent encodings based on [RFC7446].

The intent of this document is to provide a YANG data model, that can be utilized by a Multi-Domain Service Coordinator (MDSC) to collect WSON or SSON impairment data from the Provisioning Network Controllers (PNCs) to enable impairment-aware optical path computation according to the ACTN Architecture [RFC8453]. The communication between controllers is done via a NETCONF [RFC6241] or a RESTCONF interface [RFC8040].

Optical data plane interoperability, particularly for optical transponders across multiple vendors, is a complex challenge that typically necessitates joint engineering regardless of control and management plane capabilities. However, the YANG data model defined in this document provides the essential optical impairment data required for impairment-aware path computation including optical transponder interoperability if it exists.

Optical data plane interoperability is outside the scope of this document.

This document augments the generic TE topology YANG model defined in [RFC8795].

The impairment-aware topology for a WSON/SSON network based on the YANG data model defined in this document is intended to be used for exposing the network topology including optical impairments. Therefore, the topology information that is typically provided by a PNC is assumed to be read-only data. This may change when the same impairment-aware topology model is used for other optical network use cases than exposing the network topology. For example, for a path computation engine, where topological elements could be added in the context of a what-if scenario analysis. This is outside of the scope of this document.

This document defines one YANG module: ietf-optical-impairment-topology (Section 3).

1.1. Terminology

Refer to [RFC6566], [RFC7698], and [G.807] for the key terms used in this document.

The following terms are defined in [RFC7950] and are not redefined here:

* client

* server

* augment

* data model

* data node

The terminology for describing YANG data models is found in [RFC7950].

The term ROADM in this document refers to the term "multi-degree reconfigurable optical add/drop multiplexer (MD-ROADM)" as defined in [G.672]. It does not include local optical transponders, which can be co-located in the same physical device (managed entity).

The term WDM-node refers to a physical device, which is managed as a single network element.

The term WDM-TE-node refers to those parts of a WDM-node (physical device) that are modeled as a TE-node as defined in [RFC8795], which may include a ROADM and/or multiple local optical transponders (OTs). Hence, a WDM-TE-node might only contain OTs.

The term "WDM-TE-network" refers to a set of WDM-TE-nodes as defined above that are interconnected via TE-links carrying WDM signals. These TE-links may include optical amplifiers.

The term "add/drop TE-link" refers to a TE-link representing the media channel between a transceiver’s media port of a remote optical transponder (OT) and an add/drop port of the ROADM in the adjacent WDM-node. The add/drop TE-link typically carries a single optical tributary signal (OTSi, i.e., a modulated optical carrier, see Section 2.3.1).

The term "bundled add/drop TE-link" refers to the TE-link bundling concept as defined in [RFC8795]. Multiple component links, add/drop TE-links in this case, are bundled into a single bundled add/drop TE-Link.

In the context of this document, the term "layer 0" refers to the photonic layer or WDM layer network in the architecture of the optical transport network (OTN) as defined in ITU-T Recommendation

G.709 [G.709], ITU-T Recommendation G.872 [G.872], and ITU-T Recommendation G.807 [G.807] as opposed to the electrical switching layers of the OTN, which are typically referred to as layer 1 (L1). The term "layer 0" may also be used for other transport network technologies (e.g. copper-based, radio-based, or free space optics-based, etc.), which are outside the scope of this document.

The term "muxponder" is a short for "multiplexer-transponder" and refers to a device used in optical networking, especially in DWDM (Dense Wavelength Division Multiplexing) systems, to combine multiple client signals onto a single high-speed optical wavelength.

1.2. Tree Diagram

A simplified graphical representation of the data model is used in Section 2 of this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

1.3. Prefixes in Data Node Names

In this document, names of data nodes and other data model objects are prefixed using the standard prefix associated with the corresponding YANG imported modules, as shown in Table 1.

Prefix	YANG module	Reference
oit	ietf-optical-impairment-topology	[RFCXXXX]
l0-types	ietf-layer0-types	[I-D.ietf-ccamp-rfc9093-bis]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
te-types	ietf-te-types	[I-D.ietf-teas-rfc8776-update]
tet	ietf-te-topology	[RFC8795]

Table 1: Prefixes and corresponding YANG modules

[Note to RFC editor: Please replace XXXX with the number assigned to the RFC once this draft becomes an RFC.]

1.4. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. Scope of this document and Data Plane Reference Architecture

2.1. Scope of this document

The impairment-aware topology YANG model for optical networks defined in this document is a network model as defined in [RFC8969]. The topology model provides read-only network topology status information that is typically used for path computation during service provisioning when a new service is established on the network.

The model in this document does not provide device configuration capabilities. Where those capabilities are needed, a device model as defined in [RFC8969] can be used: [I-D.ietf-ccamp-dwdm-if-param-yang] defines a device model for Dense Wavelength Division Multiplexing (DWDM) interfaces.

2.2. Optical Transport Network Data Plane

This section provides a description of the optical transport network reference architecture and its relevant components and their optical impairments needed to support impairment-aware path computation.

Figure 1 shows the reference architecture.

```
     +-------------------+                      +-------------------+
     |     WDM-node 1    |                      |     WDM-node 2    |
     |                   |                      |                   |
     | PA  +-------+ BA  |          ILA         | PA  +-------+ BA  |
     | +-+ |       | +-+ |  _____  +--+  _____  | +-+ |       | +-+ |
   --|-| |-| ROADM |-| |-|-()____)-|  |-()____)-|-| |-| ROADM |-| |-|--
     | +-+ |       | +-+ |         +--+         | +-+ |       | +-+ |
     |     +-------+     | optical              |     +-------+     |
     |       | | |       |  fiber               |       | | |       |
     |       o o o       |                      |       o o o       |
     |    local          |                      |    local          |
     |    transponders   |                      |    transponders   |
     +-------------------+                      +-------------------+

                          OTS MCG        OTS MCG
                        <--------->    <--------->
                            OMS MCG = TE-link
                    <--------------------------------->
```

BA: Booster Amplifier (or egress amplifier)
PA: Pre-Amplifier (or ingress amplifier)
ILA: In-Line Amplifier
MCG: Media Channel Group [G.807]
OTS MCG: Optical Transmission Section MCG [G.807]
OMS MCG: Optical Multiplex Section MCG [G.807]

Figure 1: Reference Architecture for Optical Transport Network

BA (WDM-node 1) is the egress Amplifier and PA (WDM-node 2) is the ingress amplifier for the Optical Multiplex Section Media Channel Group (OMS MCG) [G.807] in the direction from left to right in Figure 1.

According to [G.807], clause 3.2.4, a Media Channel Group (MCG) represents "a unidirectional point-to-point management/control abstraction that represents a set of one or more media channels that are co-routed. A media channel group (MCG) is bounded by a pair of media ports."

2.3. OTS and OMS Media Channel Group

According to [G.807], an Optical Transmission Section Media Channel Group (OTS MCG) represents a topological construct between two adjacent amplifiers, such as:

(i) between a WDM-TE-node’s BA and the adjacent ILA,
(ii) between a pair of ILAs,
(iii) between an ILA and the adjacent WDM-TE-node’s PA.

[G.807] defines an OMS MCG as "The topological relationship between the media port on a filter or coupler where a set of media channels are aggregated and the media port on a filter or coupler where one or more media channel is added to or removed from that aggregate. All of the media channels that are represented by the OMS MCG must be carried over the same serial concatenation of OTS MCGs and amplifiers."

An OMS MCG originates at the ROADM in the source WDM-node and terminates at the ROADM in the destination WDM-node traversing the Booster Amplifier (BA) and the Pre-Amplifier (PA) in the WDM-nodes as well as the In-Line Amplifiers (ILAs) between the two WDM-nodes.

An OMS MCG can be decomposed into a sequence of OTS MCGs and amplifiers.

An OMS MCG traverses a sequence of optical elements between the ROADM function of two adjacent WDM-nodes as depicted in Figure 1 where the OMS MCG is terminated. These elements can be in the transmit direction: a Booster Amplifier (BA), one or more fiber sections with in-line amplifiers (ILAs), and a Pre-Amplifier (PA). A concentrated loss element can be used to describe an insertion loss caused, for example, by a fiber connector along the sequence of optical elements.

In TE-topology terms, the OMS MCG is modeled as a WDM TE-link interconnecting two WDM-TE-nodes. A network controller can retrieve the optical impairment data for all the WDM TE-link elements defined in the layer-0 topology YANG model.

The optical impairments related to the link between remote optical transponders, located in a different WDM-TE-node (an IP router with integrated optical transponders for example), can also be modeled as a WDM TE-link using the same optical impairments as those defined for a WDM TE-link between WDM-TE-nodes (OMS MCG). In this scenario, the node containing the remote optical transponders can be considered as WDM-TE-node with termination capability only and no switching capabilities.

A WDM TE-link is terminated on both ends by a link termination point (LTP) as defined in [RFC8795]. Links between WDM nodes in optical transport networks are typically bidirectional. Generally, they have different impairments in the two directions and hence they MUST be modeled as a pair of two unidirectional TE-links following the [RFC8795] modeling approach. Unlike TE-links, which are unidirectional, the LTPs on either end of the TE-link pair forming the bidirectional link, are bidirectional as described in [I-D.ietf-teas-te-topo-and-tunnel-modeling] and the pair of unidirectional links are connected to the same bidirectional LTP on either end of the link pair.

2.3.1. Optical Tributary Signal (OTSi)

The OTSi is defined in ITU-T Recommendation G.959.1, section 3.2.4 [G.959.1] as "Optical signal that is placed within a network media channel for transport across the optical network. This may consist of a single modulated optical carrier or a group of modulated optical carriers or subcarriers." The YANG model defined in Section 3 assumes that a single OTSi consists of a single modulated optical carrier. This single modulated optical carrier conveys digital information. Characteristics of the OTSi signal are modulation scheme (e.g. QPSK, 8-QAM, 16-QAM, etc.), baud rate (measure of the symbol rate), pulse shaping (e.g. raised cosine - complying with the Nyquist inter symbol interference criterion), etc.

Path computation needs to know the existing OTSi signals for each OMS link in the topology to determine the optical impairment impact of the existing OTSi signals on the optical feasibility of a new OTSi signal and vice versa, i.e., the impact of the new OTSi on the existing OTSi signals. For determining the optical feasibility of the new OTSi, it is necessary to know the OTSi properties like carrier frequency, baud rate, and signal power for all existing OTSi signals on each OMS link.

Additionally, it is necessary for each WDM-TE-node in the network to know the OTSi signals that are added to or dropped from a WDM TE-link (OMS MCG) link as well as the optical power of these OTSi signals to check whether the WDM-TE-node’s optical power constraints are met.

The impairment-aware topology YANG model for optical networks in Section 3 defines the optical OTSi properties needed for impairment-aware path computation including the spectrum occupied by each OTSi signal. The model also defines a pointer (leafref) from the OTSi to the transceiver module terminating the OTSi signal.

The OTSi signals in the YANG model are described by augmenting the network and each OTSi signal is uniquely identified by its otsi-carrier-id, which is unique within the scope of the OTSiG (see Section 2.3.2 below) the OTSi belongs to.

2.3.2. Optical Tributary Signal Group (OTSiG)

The OTSiG is defined in ITU-T Recommendation G.807 [G.807] as a "set of optical tributary signals (OTSi) that supports a single digital client". Hence, the OTSiG is an electrical signal that is carried by one or more OTSi’s. The relationship between the OTSiG and the OTSi’s is described in [G.807], section 10.2. The YANG model in Section 3 supports both cases: the single OTSi case where the OTSiG contains a single OTSi (see [G.807], Figure 10-2) and the multiple OTSi case where the OTSiG consists of more than one OTSi (see [G.807], Figure 10-3). From a layer 0 topology YANG model perspective, the OTSiG is a logical construct that associates the OTSi’s, which belong to the same OTSiG. The typical application of an OTSiG consisting of more than one OTSi is inverse multiplexing. Constraints exist for the OTSi’s belonging to the same OTSiG such as: (i) all OTSi’s must be co-routed over the same optical fibers and nodes and (ii) the differential delay between the different OTSi’s may not exceed a certain limit. Example: a 400Gbps client signal may be carried by 4 OTSi’s where each OTSi carries 100Gbps of client traffic.

All OTSiGs are described in the YANG model by augmenting the network and each OTSiG is uniquely identified by its otsi-group-id, which is unique within the network. Each OTSiG also contains a list of the OTSi signals belonging to the OTSiG.

```
                               OTSiG
        _________________________/\__________________________
       /                                                     \
                                 m=7
- - - +--------------------------X--------------------------+ - - -
/ / / |                                                     | / / /
 / / /|      OTSi         OTSi         OTSi         OTSi    |/ / /
/ / / |        ^            ^            ^            ^     | / / /
 / / /|        |            |            |            |     |/ / /
/ / / |        |            |            |            |     | / / /
 / / /|        |            |            |            |     |/ / /
 -4  -3  -2  -1   0   1   2   3   4   5   6   7   8   9  10  11  12
--+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---
                                n = 4

  X: indicates the center of the frequency slot
```

Figure 2: MC Example containing all 4 OTSi signals of an OTSiG

2.3.3. Media Channel (MC)

[G.807] defines a "media channel" as "A media association that represents both the topology (i.e., the path through the media) and the resource (i.e., frequency slot or effective frequency slot) that it occupies." In this document, the term "channel" is occasionally used to indicate the resource of an MC (i.e., frequency slot or effective frequency slot), without representing topology.

In this document, an end-to-end MC is defined as a type of MC, which is formed by the serial concatenation of all the MCs from source transceiver media ports to destination transceiver media ports. This end-to-end MC is defined across all the ROADM nodes along the end-to-end optical path with the same nominal central frequency n and frequency slot of width m, which represents the effective frequency slot of the end-to-end MC. An end-to-end MC can carry a single OTSi, or multiple OTSi signals belonging to the same OTSiG.

[G.807_Amd1] defines a "network media channel (NMC)" as "a type of media channel that is formed by the serial concatenation of all media channels between the media port of a modulator and the media port of a demodulator". The modulator and demodulator are integral functions of a transceiver and their media ports do not necessarily coincide with the media port of the transceiver, which is associated with the transceiver’s physical optical port. Due to this difference, the end-to-end MC is used in this document based on the definition in the previous paragraph.

In Section 2.11, the term "end-to-end MC path" is used to describe the topological aspect of the end-to-end MC, i.e., the path through the media (see: [G.807_Amd1], section 7.1.2). This is in line with the TE path defined in [RFC8795], section 3.9, where the TE path is defined as "an ordered list of TE links and/or TE nodes on the TE topology graph" interconnecting a pair of tunnel termination points (TTPs).

```
                                    m=8
     +-------------------------------X-------------------------------+
     |                               |                               |
     |     +----------X----------+   |   +----------X----------+     |
     |     |        OTSi         |       |        OTSi         |     |
     |     |          ^          |   |   |          ^          |     |
     |     |          |          |       |          |          |     |
    -4  -3  -2  -1   0   1   2   3   4   5   6   7   8   9  10  11  12
   --+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+-
                                    n=4

     <------------------------ Media Channel ------------------------>

     X: indicates the center of the frequency slot
```

Figure 3: MC Example containing both OTSi signals of an OTSiG

The frequency slot of the MC is defined by the n value defining the central frequency of the MC and the m value that defines the width of the MC following the flexible grid definition in [G.694.1]. In this model, the effective frequency slot as defined in [G.807] is equal to the frequency slot of this MC. It is also assumed that ROADM devices can switch MCs. For various reasons (e.g. differential delay), it is preferred to use a single MC for all OTSi’s of the same OTSiG. It may however not always be possible to find a single MC for carrying all OTSi’s of an OTSiG due to spectrum occupation along the OTSiG path.

2.3.4. Media Channel Group (MCG)

ITU-T [G.807] defines the Media Channel Group MCG as "A unidirectional point to point management/control abstraction that represents a set of one or more media channels that are co-routed." The YANG model in Section 3 assumes that the MCG is a logical grouping of one or more MCs that are used to carry all OTSi’s belonging to the same OTSiG.

The MCG can be considered as an association of MCs without defining a hierarchy where each MC is defined by its (n,m) value pair. An MCG consists of more than one MC when no single MC can be found from source to destination that is wide enough to accommodate all OTSi’s (modulated carriers) that belong to the same OTSiG. In such a case the set of OTSi’s belonging to a single OTSiG must be split across 2 or more MCs.

```
                                    MCG1 = {M1.1, M1.2}
           __________________________/\________________________
          /                                                     \
                      M1.1                  M2          M1.2
           ____________/\____________  _____/\_____  ____/\____
          /                          \/            \/           \
    - - - +---------------------------+-------------+-----------+ - - -
    / / / |                           | / / / / / / |           | / / /
     / / /|    OTSi    OTSi    OTSi   |/ / / / / / /|    OTSi   |/ / /
    / / / |     ^       ^       ^     | / / / / / / |     ^     | / / /
     / / /|     |       |       |     |/ / / / / / /|     |     |/ / /
    / / / |     |       |       |     | / / / / / / |     |     | / / /
     / / /|     |       |       |     |/ / / / / / /|     |     |/ / /
         -7    -4    -1 0 1 2 3 4 5 6 7 8    ...    14    17    20
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
                        n=0                               n=17
                K1      K2      K3                        K4
```

Figure 4: MCG Example with 2 MCs

The MCG is relevant for path computation because all end-to-end MCs belonging to the same MCG MUST be co-routed, i.e., MUST follow the same path. Additional constraints may exist (e.g. differential delay).

2.4. Optical Amplifiers

Optical amplifiers are used in WDM networks for amplifying the optical signal in the optical domain without any optical to electrical and electrical to optical conversion. Three major optical amplifier technologies are existing at the time of writing:

* Erbium Doped Fiber Amplifiers (EDFAs)
* Raman Amplifiers
* Semiconductor Optical Amplifiers (SOAs)

In today’s WDM networks EDFAs and Raman amplifiers are widely used. Raman amplifiers have become attractive due to their large spectral gain bandwidth, which can be quite flat, with similar or even lower noise figures compared to EDFAs. On the other hand, Raman amplifiers consume more power and are usually more expensive than EDFAs.

Raman amplifiers are distributed amplifiers where an optical pump signal is injected typically in opposite direction to the optical signal that is amplified (backward pump, counter-propagating pump light). Injecting the optical pump signal in the same direction is also possible (forward pump, co-propagating pump light). For optical amplifiers, the YANG model defines Raman pump light attributes describing the direction (raman-direction) with respect to the signal that is amplified and optical frequency and power for the pump light source(s) contained in the raman-pump list. These Raman amplifier-specific attributes are optional as they are only applicable to Raman amplifiers. For determining the optical amplifier type, i.e., to figure out whether an optical amplifier is a Raman amplifier, the type-variety attribute is used. Due to the distributed nature of the Raman amplifier it is difficult to clearly separate the amplifier from the fiber span into which the pump signal is injected. From a topology modeling perspective, the Raman amplifier is modeled as two OMS line elements:

1. a passive fiber element accounting for the fiber loss only and not the resulting loss including the Raman gain

2. an amplifier element providing all optical amplifier properties (gain, tilt, etc.). On the OMS-link, the amplifier element is placed where the pump is located and the geolocation information also indicates the location of the pump.

Amplifiers can be classified according to their location along the TE-link (OMS MCG). There are three basic amplifier types: In-Line Amplifiers (ILAs), Pre-Amplifiers and Booster Amplifiers. ILAs are separate physical devices while Pre-Amplifiers and Booster Amplifiers are integral elements of a WDM-node. From a data modeling perspective, node-internal details should not be modeled and should be abstracted as much as possible. For Pre-Amplifiers and Booster Amplifiers, however, a different approach has been taken, and they are modeled as TE-link elements as they have the same optical impairments as ILAs.

ILAs may have a variable optical attenuator on the ingress side (in-voa attribute) allowing control of the input power of the WDM signal (OMS MCG) entering the gain stage of the ILA. It may also have a variable optical attenuator on the egress side, which allows control of the optical power of the WDM output signal (OMS MCG) of the ILA. The actual-gain attribute reflects the gain of the ILA gain stage and does not include the attenuation of the in-voa and/or out-voa.

To support the modeling of multi-band (e.g., C + L band) and multi-stage (cascaded) amplifiers as depicted in Figure 5, the OMS element that describes an optical amplifier may contain an unordered list of amplifier-elements. The position of the element is based on the following attributes:

* lower-frequency and upper-frequency describing the frequency band the set of amplifier-elements are operating in.

* stage-order describing the sequential order of the cascaded amplifier-elements for the frequency band.

The detailed representation of the amplifier stages is not always mandatory. Abstraction is allowed as long as the optical impairments of the multi-stage amplifier are modeled properly. For example, the detailed representation of the cascaded elements is needed in case the amplifier supports both amplification of the signal as well as the DGE function described in Section 2.5.

Multi-band amplifiers like the dual-band amplifier depicted in Figure 5 have a band-separating filter at the input and a band-combining multiplexer combining all the bands at the output. These filter and multiplexer functions are not modeled explicitly and their optical impairments are subsumed in the optical impairments of the amplifier components.

```
                 Dual-band, Multi-stage Amplifier with DGE
             +-----------------------------------------------+
             |                                               |
             |                         C BAND                |
             |                  lower/upper-frequency        |
             |                            |                  |
             |                +-----------+----------+       |
             |                |                      |       |
             |                  OA1      DGE      OA2        |
             |                  |\      +---+     |\         |
             |                  | \     |   |     | \        |
         --->o---+-------------->|  +----+   +-----+  +-->+---o--->
             |   |              | /     |   |     | /    |   |
             |   |              |/      +---+     |/     |   |
             |   | stage-order = 1        2        3     |   |
             |   |                                       |   |
             |   |                                       |   |
             |   | stage-order = 1        2        3     |   |
             |   |              |\      +---+     |\     |   |
             |   |              | \     |   |     | \    |   |
             |   +-------------->|  +----+   +-----+  +-->+   |
             |                  | /     |   |     | /        |
             |                  |/      +---+     |/         |
             |                  OA1      DGE      OA2        |
             |                |                       |      |
             |                +-----------+-----------+      |
             |                            |                  |
             |                  lower/upper-frequency        |
             |                         L BAND                |
             |                                               |
             +-----------------------------------------------+
```

Figure 5: Example of a Dual-band, Multi-stage Amplifier with DGE Functionality

ILAs are placed at locations where the optical amplification of the WDM signal is required on the TE-link (OMS MCG) between two WDM-TE-nodes. Geolocation information is already defined for TE nodes in [RFC8795] and is also beneficial for ILAs. Therefore, the same geolocation container has been added to the amplifier element on an OMS link containing altitude, latitude, and longitude as optional attributes.

2.5. Dynamic Gain Equalizers

A Dynamic Gain Equalizer (DGE) is optical equipment that is capable of adjusting the optical power on a per-channel basis in order to compensate the channel power variation as a result of variable gain or loss the DWDM signals experienced while propagating through the network. The channel power can be configured explicitly or in the form of power-spectral-density.

2.6. Transponders

A transponder is optical equipment that sends and receives the optical signal from a DWDM network. A transponder can have one or more transceiver modules. A transceiver represents a transmitter and its corresponding receiver (Tx/Rx pair) as defined in ITU-T Recommendation G.698.2 [G.698.2]. In addition to the transceiver, which is terminating an OTSi signal, a transponder typically provides additional layer 1 functionality such as, for example, aggregation (multiplexing) of client traffic from multiple input ports into a single OTSi signal, which is outside the scope of this document addressing optical layer 0 aspects of transponders.

The termination of an OTSi signal by a transceiver is modeled as a function of the tunnel termination point (TTP) as defined in [RFC8795]. Because optical transport services (TE tunnels) are typically bidirectional, a TTP is also modeled as a bidirectional entity like the LTP described in Section 2.3. Moreover, a TTP can terminate one or several OTSiG signals (tunnels) as described in [I-D.ietf-teas-te-topo-and-tunnel-modeling] and each OTSiG consists of one or multiple OTSi signals as described in Section 2.3.2. Therefore, a TTP can be associated with multiple transceivers.

A transponder is typically characterized by its data/symbol rate and the maximum distance the signal can travel. Other transponder properties are for example but are not limited to: carrier frequency range for the optical channel, output power per channel, measured input power, modulation scheme, Forward Error Correction (FEC), etc.

From a path computation perspective, the selection of the compatible configuration of the source and the destination transceivers is an important factor for optical signals to traverse through the DWDM network.

The YANG model defines three different approaches to describe the transceiver capabilities (called "modes") that are needed to determine optical signal compatibility:

* Standard Modes

* Organizational Modes

* Explicit Modes

2.6.1. Standard Modes

A standard mode is related to an optical specification developed by a Standards Development Organization (SDO). Currently, the "Standard Modes" can only be referred to ITU-T Recommendation G.698.2 [G.698.2] since ITU-T Recommendation G.698.2 is the only standard defining "Standard Modes" today. Nothing is precluding, however, consideration of other specifications provided by any other SDO in the Standard Mode context as soon as such specifications might be available. An application code as defined in ITU-T G.698.2 [G.698.2] represents a standard ITU-T G.698.2 optical interface specification towards the realization of transversely compatible DWDM systems that it is a standard that ensures transceivers from different vendors can work together in a DWDM network. Two transceivers supporting the same application code and a line system matching the constraints, defined in ITU-T G.698.2, for that application code will interoperate. As the characteristics are encoded in the application code, the YANG model in this document only defines a string, which represents that application code.

For the standard modes, some additional attributes are defined. The most important one is the line-coding-bitrate attribute, which was added because [G.698.2] lists 100gpbs application codes supporting two data formats, an OTU4 related data format and a Flex-O related data format. The supported data formats for an application code can be described by listing the supported data formats via the line-coding-bitrate attribute as a transceiver capability.

Moreover, the transceiver properties like optical carrier frequency range, optical carrier tunability, and transmitter/receiver optical power ranges can be described as optional attributes in case they differ from the specification for the standard mode, i.e., as defined in [G.698.2]. A transceiver may support extended optical frequency ranges or optical power ranges or a finer optical carrier tunability. These capabilities can be described explicitly if needed.

2.6.2. Organizational Modes

Organizations like operator groups, industry fora, or equipment vendors can define their own optical interface specifications and make use of transceiver capabilities going beyond existing standards.

An organizational mode is identified by the organization-identifier attribute defining the scope and an operational-mode that is meaningful within the scope of the organization. Hence, the two attributes MUST always be considered together. It is the responsibility of the organization to assign operational modes and to ensure that operational modes are unique and unambiguous within the scope of the organization.

Two transceivers can be interconnected, if they have at least one (organization-identifier, operational-mode) pair in common and if the supported carrier frequency and power attributes have a matching range. This is a necessary condition for path computation in the context of organizational modes.

An operational mode is a transceiver preset (a configuration with well-defined parameter values) subsuming several transceiver properties defined by the optical interface specification - these properties are not provided for an operational mode and are therefore not defined in the YANG model. Examples of these properties are:

* FEC type

* Modulation scheme

* Encoding (mapping of bit patterns (code words) to symbols in the constellation diagram)

* Baud rate (symbol rate)

* Carrier bandwidth (typically measured in GHz)

The major reason for these transceiver presets is the fact that the attribute values typically cannot be configured independently and are therefore advertised as supported operational mode capabilities. It is the responsibility of the organization to assign operational modes and to ensure that operational modes are unique and not ambiguous within the scope of the organization.

In addition to the transceiver properties subsumed by the operational mode, optical power and carrier frequency related properties are modeled separately, i.e., outside of the operational mode. This modeling approach allows transponders using different transceiver variants (e.g. optical modules) with slightly different power and/or frequency range properties to interoperate without defining separate operational modes. Different optical modules (pluggables) from different suppliers typically have slightly different input and output power ranges or may have slightly different carrier frequency tuning ranges.

The received channel power and the received total power are two parameters that can be measured by the receiver and can be provided by the transceiver in order to allow a controller to determine the expected performance of the end-to-end service taking into account the optical impairments along the path.

An organization MAY define the operational modes to include the optical power and carrier frequency related properties following the application code approach as defined in ITU-T Recommendation G.698.2 [G.698.2]. In such a case, the explicit optical power and carrier frequency related optional attributes should be omitted in order to avoid redundant information in the description of the transceiver capabilities. If these attributes are provided in addition to the operational modes including these attribute values implicitly, the parameter values provided explicitly replace the implicit values and take precedence. This should, however, only be done in exceptional cases and should be avoided whenever possible. In case an implicitly given range is extended utilizing the explicit optional attributes, a path computation policy rule may be applied to select a value preferably from the range defined implicitly and to only select a value from the extended range if no path can be found for values in the implicitly defined range. Path computation policy is outside the scope of this topology YANG model.

In summary, the optical power and carrier frequency related attributes shall either be described implicitly by the operational mode following the definition provided by that organization or shall be described explicitly when the optical power and carrier frequency related properties are not included in the operational mode definition.

2.6.3. Explicit Modes

The explicit mode allows the encoding, explicitly, of any subset of parameters e.g., FEC type, Modulation type, etc., to enable a controller entity to check for interoperability by means outside of this document. It shall be noted that using the explicit encoding does not guarantee interoperability between two transceivers even in case of identical parameter definitions. The explicit mode shall therefore be used with care, but it could be useful when no common Application Codes or Organizational Modes exist or the constraints of common Application Codes or Organizational Modes cannot be met by the line system.

2.6.4. Transponder Capabilities and Current Configuration

The YANG model described in Section 3 defines the optical transceiver properties. They are divided between:

a. Optical transceiver capabilities, describing how it can be configured

b. Current transceiver setting, indicating how it is currently configured

The transceiver capabilities are described by the set of modes the transceiver is supporting. Each mode must follow only one of the three mode options defined in Section 2.6.1, Section 2.6.2, and Section 2.6.3 (choice in the YANG model). The YANG model allows the description of the transceiver capabilities by mixing different modes. A transceiver may support some ITU-T application codes and in addition some organizational or explicit modes.

A transceiver mode description comprises the following properties:

* Supported transmitter tuning range with min/max nominal carrier frequency [f_tx_min, f_tx_max]

* Supported transceiver tunability describing the transmitter’s frequency fine tuning granularity (the minimum distance between two adjacent carrier frequencies in GHz)

* Supported transmitter power range [p_tx-min, p_tx_max]

* Supported receiver channel power range [p_rx-min, p_rx_max]

* Supported maximum total power, rx power for all channels fed into the receiver

These optical transceiver properties are explicitly defined in the model for explicit and organizational modes, while they are implicitly defined for the application codes (see ITU-T G698.2 [G.698.2]).

The set of optical impairment limits, e.g., min optical signal to noise ratio (OSNR), max polarization mode dispersion (PMD),max chromatic dispersion (CD), max polarization dependent loss (PDL), quality factor (Q-factor) limit, are explicitly defined for the explicit modes while they are defined implicitly for the application codes and organizational modes.

The model provides information about the maximum accumulated impairments supported by the transceiver modes (i.e., max-chromatic-dispersion, max-polarization-dependent-loss, max-polarization-mode-dispersion, max-diff-group-delay). For CD, PMD and PDL impairments, the model also supports the option to provide more detailed OSNR penalties as a function of the accumulated impairments (i.e., cd-penalty, pmd-penalty and pdl-penalty). In this case the attributes providing the maximum accumulated impairments MAY be omitted and the maximum accumulated impairment MUST be listed in the penalty list. In case both are present, there MUST NOT be any value in the penalty list above the maximum accumulated impairment.

It is possible that the set of parameter values defined for an explicit mode may also be represented in form of an organizational mode or one or more application codes. The "compatible-modes" container may provide two different lists with pointers to application codes and organizational modes, respectively.

The current transponder configuration describes the properties of the OTSi transmitted or received by the transceiver attached to a specific transponder port.

Each OTSi has the following three pointer attributes modeled as leafrefs:

* Pointer to the transponder instance containing the transceiver terminating the OTSi

* Pointer to the transceiver instance terminating the OTSi

* Pointer to the currently configured transceiver mode

Additionally, the OTSi is described by the following frequency and optical power related attributes:

* current carrier-frequency

* currently transmitted channel power

* currently received channel power

* currently received total power

2.7. 3R Regenerators

Optical transponders are usually used to terminate a layer 0 tunnel (layer 0 service) in the WDM layer. If, however, no optical path can be found from the source transponder to the destination transponder that is optically feasible due to the optical impairments, one or more 3R regenerators are needed for regenerating the optical signal in intermediate nodes. The term "3R" regenerator means: reamplification, reshaping, retiming. As described in [G.807], Appendix IV, a 3R regenerator terminates the OTSi and generates a new OTSi. Depending on the 3R regenerator capabilities, it can provide functions such as carrier frequency translation (carrier-frequency), changes in the modulation scheme (modulation-type) and FEC (FEC-type) while passing through the digital signal except the FEC (the FEC is processed and errors are corrected).

The 3R regeneration compound function is illustrated in section 10.1 of [G.798.1], and sections 10.3 and 10.4 provide examples of a ROADM architecture and a photonic cross-connect architecture including 3R regenerators. Based on the functionality provided, 3R regenerators are considered as topological layer 0 entities because they are needed for layer 0 path computation in case the optical impairments make it impossible to find an optically feasible end-to-end path from the source transponder to the destination transponder without 3R regeneration. When an end-to-end path includes one or more 3R regenerators, the corresponding layer 0 tunnel is subdivided into 2 or more segments between the source transponder and the destination transponder terminating the layer 0 tunnel.

3R regenerators are usually realized by a pair of optical transponders, which are described in Section 2.6. If a pair of optical transponders is used to perform a 3R regeneratator function, two different configurations are possible involving the pair of optical transceivers of the two optical transponders:

* The two transponders can be operated in a back-to-back configuration where the transceiver of each optical transponder receives and transmits the optical signal from/to the same segment of the end-to-end tunnel. This means that each transceiver is operated in a bi-directional mode.

```
           Optical Transponder 1        Optical Transponder 2
          +------------------------+    +------------------------+
          | Transceiver            |    |            Transceiver |
          |-------------+   +------|    |-----+   +-------------|
      --->| Receiver    |---|Sig.  |--->|Sig. |---| Transmitter |--->
          |-------------+   |      |    |     |   +-------------|
      <---| Transmitter |---|Proc.|<---|Proc.|---|    Receiver |<---
          |-------------+   +------|    |-----+   +-------------|
          |                        |    |                        |
          +------------------------+    +------------------------+

          Sig. Proc. = Signal Processing
```

Figure 6: Back-to-back 3R Regenerator Example

* The two transponders can be operated in a configuration where each transponder performs the 3R regeneration function in one direction, one in forward direction (from source to destination) and the other in the reverse direction. In this configuration, the transceiver of each optical transponder receives the signal from one segment and transmits the regenerated optical signal into the adjacent segment. This configuration is also called cross-regeneration and each transceiver is operated in a uni-directional mode.

  Implementations MAY support the change of the carrier frequency where the receiver may operate at a different optical frequency than the transmitter. The transceiver mode is a property of the transceiver and is applied to the transmitter and the receiver. Therefore, the transceiver mode is the same for the two segments on the two sides of the 3R regeneratator realized by two transceivers operated in the uni-directional mode.

```
                             Optical Transponder 1
                             3R in forward direction
                         +-----------------------------+
                         | Transceiver                 |
                         |-------------+   +---------+ |
                  ------->| Receiver    |---|Sig. --+ | |
                         |-------------+   |       | | |
                     +---| Transmitter |---|Proc.<-+ | |
                     |   |-------------+   +---------+ |
                     |   |                             |
                     |   +-----------------------------+
                     |
                     +----------------------------------------->

                 <-----------------------------------------+
                                                           |
                         +-----------------------------+   |
                         |                 Transceiver |   |
                         | +---------+   +-------------|   |
                         | | +->Sig. |---| Transmitter |---+
                         | | |       |   +-------------|
                         | | +--Proc.|---| Receiver    |<-------
                         | +---------+   +-------------|
                         |                             |
                         +-----------------------------+
                             Optical Transponder 2
                             3R in backward direction

                         Sig. Proc. = Signal Processing
```

Figure 7: Cross-3R Regenerator Example

Since 3R regenerators are composed of an optical transponder pair, the capability that an optical transponder can be used as a 3R regenerator is added to the transponder capabilities. Hence, no additional entity is required for describing 3R regenerators in the TE-topology YANG model. The optical transponder capabilities regarding the 3R regenerator function are described by the following two YANG model attributes:

* supported-termination-type

* supported-3r-mode

The supported-termination-type attribute describes whether the optical transponder can be used as tunnel terminating transponder only, as 3R regenerator only, or whether it can support both functions. The supported-3r-mode attribute describes the configuration of the transponder pair forming the 3R regenerator.

2.8. Wavelength Selective Switch (WSS)/Filter

A WSS is a device that dynamically routes individual wavelengths from a common input fiber to any of several output ports without converting them into electrical signals. The WSS/Filter is internal to a ROADM device. This document does not model the internals of a ROADM’s WSS.

2.9. Optical Fiber

There are various optical fiber types defined by ITU-T. For optical feasibility calculation, several fiber-level parameters need to be taken into account, such as, fiber-type, length, loss coefficient, PMD, connectors (in/out).

The loss of a fiber span can be described in two ways:

i. As calculated loss using the provided loss coefficient (loss-coef) and length of the fiber.

ii. As measured loss provided by the total-loss attribute.

The total-loss SHOULD be provided when it can be measured with a power measurement facility at the output of the upstream node (input of the fiber span) and a power measurement facility at the input of the downstream node (output of the fiber span). This measured loss typically differs from the calculated loss because it includes all loss contributions including possible accumulated loss due to imperfect fiber splices and connector losses. It can also change over time due to changing fiber conditions, e.g., in case of a fiber cut. In case the total-loss cannot be measured (no power measurement facilities in place), the total-loss defined as optional leaf in the YANG model SHALL be omitted.

N.B.: In case of Raman amplifiers, the Raman gain SHALL NOT be included in the measured loss to properly reflect only the loss of the fiber span in the total-loss attribute.

ITU-T G.652 defines Standard Singlemode Fiber; G.654 Cutoff Shifted Fiber; G.655 Non-Zero Dispersion Shifted Fiber; G.656 Non-Zero Dispersion for Wideband Optical Transport; G.657 Bend-Insensitive Fiber. There may be other fiber-types that need to be considered.

2.10. WDM-node Architectures

The WDM-node architectures in today's dense wavelength division multiplexing (DWDM) networks can be categorized as follows:

* Integrated WDM-node architecture with local optical transponders

* Integrated WDM-node architecture with local optical transponders and single channel add/drop ports for remote optical transponders

* Disaggregated WDM-node architecture where the WDM-TE-node is composed of degree, add/drop, and optical transponder subsystems handled as separate WDM-nodes

The TE topology YANG model augmentations for DWDM networks including optical impairments defined in Section 3 intends to cover all the 3 categories of WDM-node architectures listed above. In the case of a disaggregated WDM-node architecture, it is assumed that the optical domain controller already performs some form of abstraction and presents the WDM-TE-node representing the disaggregated WDM-nodes in the same way as an integrated WDM-TE-node with local optical transponders if the optical transponder subsystems and the add/drop subsystems are co-located (short fiber links are not imposing any significant optical impairments).

The different WDM-node architectures are briefly described and illustrated in the following subsections.

2.10.1. Integrated WDM-node Architecture with Local Optical Transponders

Figure 1 and Figure 8 below show the typical architecture of an integrated WDM-node, which contains the optical transponders as an integral part of the WDM-node. Such an integrated WDM-node provides DWDM interfaces as external interfaces for interconnecting the device with its neighboring WDM-node (see OMS MCG in Figure 1). The number of these interfaces denote also the degree of the WDM-node. A degree 3 WDM-node for example has 3 DWDM links that interconnect the WDM-node with 3 neighboring WDM-nodes. Additionally, the WDM-node provides client interfaces for interconnecting the WDM-node with client devices such as IP routers or Ethernet switches. These client interfaces are the client interfaces of the integrated optical transponders.

```
                    . . . . . . . . . . . . . . . . . .
                    .           WDM-TE-node           .
              +-----.-------------------------------- .-----+
              |     .             WDM-node            .     |
              |     .   /|  +-----------------+  |\   .     |
         Line |     .  / |--|                 |--| \  .     | Line
         WEST |  /| . |  |--|                 |--|  | . |\  | EAST
        ------+-/ |-.-|  |--|  photonic       |--|  |-.-| \-+------
        ------+-\ |-.-|  |--|  cross-connect  |--|  |-.-| /-+------
              |  \| . |  |--|                 |--|  | . |/  |
              |     .  \ |--|                 |--| /  .     |
              |     .   \|  +-----------------+  |/   .     |
              |     .                                 .     |
              |     .     +---+ +---+ +---+ +---+     .     |
              |     .     | O | | O | | O | | O |     .     |
              |     .     | T | | T | | T | | T |     .     |
              |     .     +---+ +---+ +---+ +---+     .     |
              |     .      | |   | |   | |   | |      .     |
              +-----.------+-+---+-+---+-+---+-+------.-----+
                    . . . .|.| . |.| . |.| . |.|. . . .
                           | |   | |   | |   | |
                             Client Interfaces
```

Figure 8: Integrated WDM-node Architecture with Local Transponders

2.10.2. Integrated WDM-node with Integrated Optical Transponders and Single Channel Add/Drop Interfaces for Remote Optical Transponders

Figure 9 below shows the extreme case where all optical transponders are not integral parts of the WDM-node but are separate devices that are connected to the add/drop ports of the WDM-node. If the optical transponders and the WDM-node are co-located and if short single channel fiber links are used to interconnect the optical transponders with an add/drop port of the WDM-node, the optical domain controller MAY present these optical transponders in the same way as local optical transponders. If, however, the optical impairments of the single channel fiber link between the optical transponder and the add/drop port of the WDM-node cannot be neglected, it is necessary to represent the fiber link with its optical impairments in the topology model. This also implies that the optical transponders belong to a separate TE-node.

Appendix C provides a modeling example for a configuration where the optical transponders and the ROADM are different WDM-TE-nodes (remote OT configuration).

```
                    . . . . . . . . . . . . . . . . . .
                    .           WDM-TE-node           .
              +-----.-------------------------------- .-----+
              |     .            WDM-node             .     |
              |     .   /|  +-----------------+  |\   .     |
         Line |     .  / |--|                 |--| \  .     | Line
         WEST |  /| . |  |--|                 |--|  | . |\  | EAST
        ------+-/ |-.-|  |--|  photonic       |--|  |-.-| \-+------
        ------+-\ |-.-|  |--|  cross-connect  |--|  |-.-| /-+------
              |  \| . |  |--|                 |--|  | . |/  |
              |     .  \ |--|                 |--| /  .     |
              |     .   \|  +-----------------+  |/   .     |
              +-----.---------|----|---|----|---------.-----+
           OT       .       +-+   ++   ++   +-+       .
           line I/F .       |     |     |     |       .
                    .     +---+ +---+ +---+ +---+     .
                    .     | O | | O | | O | | O |     .
                    .     | T | | T | | T | | T |     .
                    .     +---+ +---+ +---+ +---+     .
                    . . . .|.| . |.| . |.| . |.|. . . .
                           | |   | |   | |   | |
                             Client Interfaces
```

Figure 9: Integrated WDM-node Architecture with Remote Transponders

2.10.3. Disaggregated WDM-TE-node Subdivided into Degree, Add/Drop, and Optical Transponder Subsystems

Some DWDM network operators are demanding WDM subsystems from their vendors. An example is the OpenROADM project [OpenROADM] where multiple operators and vendors are developing related YANG models. The subsystems of a disaggregated WDM-TE-node are:

* Single degree subsystems

* Add/drop subsystems

* Optical transponder subsystems

These subsystems are separate network elements and each network element provides a separate management and control interface. The subsystems are typically interconnected using short fiber patch cables and form together a disaggregated WDM-TE-node. This disaggregated WDM-TE-node architecture is depicted in Figure 10 below.

As this document defines TE topology YANG model augmentations for the TE topology YANG model [RFC8795] provided at the north-bound interface of the optical domain controller, it is a valid assumption that the optical domain controller abstracts the subsystems of a disaggregated WDM-TE-node and presents the disaggregated WDM-TE-node in the same way as an integrated WDM-node hiding all the interconnects that are not relevant from an external TE topology view.

```
                   . . . . . . . . . . . . . . . . .  .
                   .            WDM-TE-node           .
             +-----.----------+            +----------.-----+
             | Degree 1       |            |       Degree 2 |
        Line |     .  +-----+ |            + +-----+  .     | Line
         1   |  /| .  |  W  |-|------------|-|  W  |  . |\  |  2
        -----+-/ |-.--|  S  ********  ********  S  |--.-| \-+------
        -----+-\ |-.--|  S  | |    *  *    | |  S  |--.-| /-+------
             |  \| .  |     |-|-+  *  *  +-|-|     |  . |/  |
             |     .  +-+-+-+ | |  *  *  | | +-+-+-+  .     |
             +-----.----|-----+ |  *  *  | +-----|----.-----+
                   .    |       |  *  *  |       |    .
             +-----.----|-----+ |  *  *  | +-----|----.-----+
             | Degree 4 |     | |  *  *  | |     | Degree 3 |
        Line |     .  +-----+ | |  *  *  | | +-----+  .     | Line
         4   |  /| .  |  W  |-|-|--*--*--+ | |  W  |  . |\  |  3
        -----+-/ |-.--|  S  | | +--*--*----|-|  S  |--.-| \-+------
        -----+-\ |-.--|  S  |-|----*--*----|-|  S  |--.-| /-+------
             |  \| .  |     | |    *  *    | |     |  . |/  |
             |     .  +--*--+ |    *  *    | +--*--+  .     |
             +-----.-----*----+    *  *    +----*-----.-----+
                   .     *         *  *         *     .
                   .  +--*---------*--*---------*--+  .
                   .  |          ADD               |  .
                   .  |          DROP              |  .
                   .  +----------------------------+  .
         Colored OT  .     |     |     |     |     .
          Line I/F   .   +---+ +---+ +---+ +---+   .
                     .   | O | | O | | O | | O |   .
                     .   | T | | T | | T | | T |   .
                     .   +---+ +---+ +---+ +---+   .
                     . . .|.| . |.| . |.| . |.|. . .
                          | |   | |   | |   | |
                            Client Interfaces
```

Figure 10: Disaggregated WDM-TE-node Architecture with Remote Transponders

2.10.4. Optical Impairments Imposed by WDM-TE-nodes

When an optical OTSi signal traverses a ROADM node, optical impairments are imposed on the signal by various passive or active optical components inside the ROADM node. Examples of optical impairments are:

* Chromatic dispersion (CD)

* Polarization mode dispersion (PMD)

* Polarization dependent loss (PDL)

* Optical amplifier noise due to amplified spontaneous emission (ASE)

* In-band cross-talk

* Filtering effects (out of scope of this document)

A ROADM node contains a wavelength selective photonic switching function (WSS)that can switch media channels (MCs) described in Section 2.3.4. These MCs can be established between two line ports of the ROADM or between a line port and an Add/Drop port of the ROADM. The Add/Drop ports of a ROADM are those ports to which optical transponders are connected. Typically, add/drop ports are used for a single optical channel signal (single OTSi), but principally this could also be a group of OTSi signals (OTSiG). The optical impairments associated with these MCs are different and the paths of the MCs inside the ROADM node can be categorized as follows:

* Express path: MC path between two line ports of the ROADM (unidirectional)

* Add Path: MC path from an Add port to a line port of the ROADM

* Drop path: MC path from a line port to a Drop port of the ROADM

Due to the symmetrical architecture of the ROADM node, the optical impairments associated with the express path are typically the same between any two line ports of the ROADM whereas the optical impairments for the add and drop paths are different and therefore MUST be modeled separately.

The optical impairments associated with each of the three types of ROADM-node-internal paths listed above are modeled as optical impairment parameter sets. These parameter sets are modeled as an augmentation of the te-node-attributes defined in [RFC8795]. The te-node-attributes are augmented with a list of roadm-path-impairments for the three ROADM path types distinguished by the impairment-type. Each roadm-path-impairments list entry contains the set of optical impairment parameters for one of the three path types indicated by the impairment-type. For the optical feasibility calculation based on the optical impairments, it is necessary to know whether the optical power of the OTSi stays within a certain power window. This is reflected by some optical power related parameters such as loss parameters or power parameters (see also [G.680]), which are included in the optical impairment parameter sets (see tree view in Appendix A).

[RFC8795] defines a connectivity matrix and a local link connectivity list for the TE node. The connectivity matrix describes the connectivity for the express paths between the different lines of the ROADM and the local link connectivity list describes the connectivity for the Add and Drop paths of the ROADM. These matrices are augmented with a new roadm-path-impairment matrix element, an add-path-impairment, and drop-path-impairment matrix element, respectively, which are defined as a pointer to the corresponding entry in the roadm-path-impairments list (leaf-ref).

2.11. Optical Protection Architectures

The YANG model defined in this document supports the following optical protection architectures:

* Individual OTSi protection

* OMS MCG protection = TE-link protection between adjacent WDM-TE-nodes

2.11.1. Individual OTSi Protection

Individual OTSi protection is a protection architecture where an individual OTSi signal is protected as described in Appendix III of ITU-T Recommendation G.873.1 [G.873.1]. This protection architecture requires specific photonic protection functions in the optical domain that are typically provided by specific protection hardware. These photonic protection functions are a photonic splitter function splitting the OTSi signal in the transmit direction and a photonic selector function selecting the OTSi signal in the receive direction from one of the two protection legs between the two protection functions terminating the individual OTSi protection. This individual OTSi protection scheme can be considered as a photonic 1+1 protection scheme (1+1 sub-network connection protection (SNCP) in ITU-T terminology).

To achieve short protection switching times, it is necessary that the OTSi signals of the two legs are identical in terms of wavelength, modulation format, FEC, etc., which means no receiver configuration changes when a protection switch at the selector occurs selecting the other leg. This is important when 3R regenerators are needed between the two end-points terminating the protected segment, which typically is end-to-end.

In case of individual OTSi protection without 3R regenerators, two end-to-end MC paths are associated with the OTSi signal. In the YANG model, this is modeled as leaf list of the OTSi providing the e2e-mc-path-id for the two end-to-end MC paths associated with the individually 1+1 protected OTSi. This scenario is depicted in Figure 11 (forward direction) and Figure 12 (reverse direction) below.

```
                           end-to-end MC path1
        |------------------------------------------------------->|

   +-----------+                                          +-----------+
   | WDM Node1 |           +-----+      +-----+           | WDM Node2 |
   |      +----|           | WDM |      | WDM |           |----+      |
   |      |   -o---------->o-----o----->o-----o---------->o-   |      |
   |  OT  |  / |           |Node3|      |Node4|           | \  |  OT  |
   | +--+ | /  |           +-----+      +-----+           |  \ | +--+ |
  -o-o  o-o-   |                                          |   -o-o  o-o-
   | +--+ | \  |     +-----+     +------+     +-----+     |  / | +--+ |
   |      |  \ |     | WDM |     | WDM  |     | WDM |     | /  |      |
   |      |   -o---->o-----o---->o------o---->o-----o---->o-   |      |
   |      +----|     |Node5|     | Node6|     |Node7|     |----+      |
   |   Splitter|     +-----+     +------+     +-----+     |Selector   |
   +-----------+                                          +-----------+

        |------------------------------------------------------->|
                           end-to-end MC path2
```

Figure 11: Individual OTSi Protection without 3R regenerators (forward direction)

```
                         end-to-end MC path1'
       |<--------------------------------------------------------|

    +-----------+                                          +-----------+
    | WDM Node1 |          +-----+      +-----+            | WDM Node2 |
    |      +----|          | WDM |      | WDM |            |----+      |
    |      |   -o<----------o-----o<-----o-----o<----------o-   |      |
    |  OT  |  / |          |Node3|      |Node4|            | \  |  OT  |
    | +--+ | /  |          +-----+      +-----+            |  \ | +--+ |
   -o-o  o-o-   |                                          |   -o-o  o-o-
    | +--+ | \  |    +-----+     +-------+     +-----+     |  / | +--+ |
    |      |  \ |    | WDM |     | WDM   |     | WDM |     | /  |      |
    |      |   -o<----o-----o<----o------o<----o-----o<----o-   |      |
    |      +----|    |Node5|     | Node6 |     |Node7|     |----+      |
    |   Selector|    +-----+     +-------+     +-----+     |Splitter   |
    +-----------+                                          +-----------+

       |<--------------------------------------------------------|
                         end-to-end MC path2'
```

Figure 12: Individual OTSi Protection without 3R regenerators (reverse direction)

For each OMS MCG (TE-link) along the two end-to-end MC paths in the forward direction (end-to-end MC path1 and end-to-end MC path2) as well as the two end-to-end MC paths in the reverse direction (end-to-end MC path1' and end-to-end MC path2'), the e2e-mc-path-id is provided for the individually protected OTSi signal. Based on this information, it is possible to construct the end-to-end MC paths between the optical transponders terminating the individually 1+1 protected OTSi.

In the scenario depicted in Figure 11 and Figure 12, the e2e-mc-path-id of end-to-end MC path1 and end-to-end MC path1' is provided for the TE-links between WDM Node1 and WDM Node3, WDM Node3 and WDM Node4 as well as WDM Node4 and WDM Node2 while the e2e-mc-path-id of end-to-end MC path2 and end-to-end MC path2' is provided for the TE-links between WDM Node1 and WDM Node5, WDM Node5 and WDM Node6, WDM Node6 and WDM Node7 as well as WDM Node7 and WDM Node2.

If a 3R regenerator is crossed on one of the two legs or even on both legs, the end-to-end MCs are terminated on both sides of the 3R regenerator. The configured-termination-type attribute set to "3r-regeneration" SHALL be used to indicate that the transceivers are forming a 3R regenerator instead of terminating the layer 0 tunnel (layer 0 service). At WDM-nodes containing a 3R regenerator, the end-2-end MCs are stitched together forming the end-to-end path for the layer 0 tunnel (layer 0 service). This is reflected in the leaf list of the OTSi, which now lists all e2e-mc-path-ids of the end-to-end MC paths on the two legs of the individually 1+1 protected OTSi signal.

In the scenario depicted in Figure 13 and Figure 14 below where a 3R regenerator is crossed in WDM Node6 on the lower leg, the e2e-mc-path-id leaf list has 3 entries (assumption: the same e2e-mc-path-id can be used for the path in the forward and reverse directions):

1. The e2e-mc-path-id identifying end-to-end MC path1 from WDM Node1 via WDM Node3 and WDM Node4 to WDM Node2 as well as end-to-end MC path1’ in the reverse direction (upper leg)

2. The e2e-mc-path-id identifying end-to-end MC path2 from WDM Node1 via WDM Node5 to WDM Node6 containing the 3R regenerator as well as end-to-end MC path2’ in the reverse direction (left hand segment of the lower leg)

3. The e2e-mc-path-id identifying end-to-end MC path3 from WDM Node6 containing the 3R regenerator via WDM Node7 to WDM Node2 as well as end-to-end MC path3’ in the reverse direction (right hand segment of the lower leg)

Based on this modeling approach it is possible to identify the end-2-end MCs stitched together at 3R regenerators on each of the two legs of the individually protected 1+1 OTSi signal. Similarly, for the case without 3R regenerators it is also possible to associate two end-to-end paths in the forward and reverse directions for the two legs between the optical transponders terminating the individually 1+1 protected OTSi in WDM Node1 and WDM Node2, respectively:

1. end-to-end MC path1 and end-to-end MC path1’ (upper leg)
2. end-to-end MC path2 and end-to-end MC path2’ stitched together with end-to-end MC path3 and end-to-end MC path3’ (lower leg)

```
                           end-to-end MC path1
        |------------------------------------------------------->|

   +-----------+                                          +-----------+
   | WDM Node1 |           +-----+      +-----+           | WDM Node2 |
   |      +----|           | WDM |      | WDM |           |----+      |
   |      |   -o---------->o-----o----->o-----o---------->o-   |      |
   |  OT  |  / |           |Node3|      |Node4|           | \  |  OT  |
   | +--+ | /  |           +-----+      +-----+           |  \ | +--+ |
  -o-o  o-o-   |                                          |   -o-o  o-o-
   | +--+ | \  |     +-----+     +------+     +-----+     |  / | +--+ |
   |      |  \ |     |     |     | +--+ |     |     |     | /  |      |
   |      |   -o---->o-----o---->o-o  o-o---->o-----o---->o-   |      |
   |      +----|     | WDM |     | +--+ |     | WDM |     |----+      |
   |   Splitter|     |Node5|     |  3R  |     |Node7|     |Selector   |
   +-----------+     +-----+     +------+     +-----+     +-----------+
                                 WDM Node6
                                 with 3R
                                 Regenerator

        |------------------------>|  |------------------------>|
            end-to-end MC path2            end-to-end MC path3
```

Figure 13: Individual OTSi Protection with a 3R regenerator
(forward direction)

```
                           end-to-end MC path1’
        |<-------------------------------------------------------|

   +-----------+                                          +-----------+
   | WDM Node1 |           +-----+      +-----+           | WDM Node2 |
   |      +----|           | WDM |      | WDM |           |----+      |
   |      |   -o<----------o-----o<-----o-----o<----------o-   |      |
   |  OT  |  / |           |Node3|      |Node4|           | \  |  OT  |
   | +--+ | /  |           +-----+      +-----+           |  \ | +--+ |
  -o-o  o-o-   |                                          |   -o-o  o-o-
   | +--+ | \  |     +-----+     +------+     +-----+     |  / | +--+ |
   |      |  \ |     |     |     | +--+ |     |     |     | /  |      |
   |      |   -o<----o-----o<----o-o  o-o<----o-----o<----o-   |      |
   |      +----|     | WDM |     | +--+ |     | WDM |     |----+      |
   |   Selector|     |Node5|     |  3R  |     |Node7|     |Splitter   |
   +-----------+     +-----+     +------+     +-----+     +-----------+
                                 WDM Node6
                                 with 3R
                                 Regenerator

        |<-------------------------|  |<-------------------------|
            end-to-end MC path2’          end-to-end MC path3’
```

Figure 14: Individual OTSi Protection with a 3R regenerator (reverse direction)

Individual OTSi protection use cases:

(i) OT and OTSi protection function are an integral part of the WDM-TE-node

(ii) OT and OTSi protection/ROADM functions are in two adjacent WDM-TE-nodes (remote OT)

(iii) OT and OTSi protection function are both in the adjacent WDM-TE-node (protected remote OT)

The different use cases are described in the following sub-sections and examples are provided as to how these uses cases can be modeled properly using the impairment-aware TE-topology YANG data model for optical networks.

2.11.1.1. OT and OTSi protection function are an integral part of the WDM-TE-node

This use case is based on the architecture illustrated in Figure 8 and the following entities are all integral parts of the WDM-TE-node:

* Local optical transponder
* Splitter/selector protection function
* ROADM function

Figure 15 illustrates such a WDM-TE-node configuration in the transmit/forward direction where the protection function is an optical splitter and Figure 16 illustrates the same WDM-TE-node configuration in the receive/reverse direction where the protection function is an optical selector selecting one of the two incoming OTSi signals and switching to the other incoming OTSi signal when the optical power of the selected OTSi signal drops below a pre-defined threshold.

The TE-topology YANG model has been augmented to describe this protection architecture. The already existing optional protection-type leaf of the TTP associated with the optical transceiver is used to indicate whether the TTP is protected, i.e., whether it is connected to a protection function or whether it is unprotected, i.e., whether it is directly connected to an add-drop port of the ROADM function in the WDM-TE-node.

For unprotected TTPs associated with an optical transceiver, the local-link-connectivity list (LLCL) as defined in [RFC8795] describes the potential connectivity between the TTP and the LTPs of the WDM-TE-node that are the local end-points of the TE-links (OMS MCGs) interconnecting the WDM-TE-node with its neighbors, also often called degrees of the WDM-TE-node as opposed to its add-drop ports.

For protected TTPs, the local-link-connectivity list has been augmented such that the potential connectivity can now be described between the TTP and multiple LTPs including the related optical impairments. Without this new capability, it was only possible to describe the potential connectivity between a TTP and a single LTP (unprotected case). If the optical impairments are the same for all local-link-connectivity list entries for a particular TTP, which is usually the case, the optical impairments should be omitted for the additional LTPs leading to a more compact topology description. If the optical impairments are different, however, they can be described for each additional LTP entry separately.

A local-link-connectivity list example for a protected TTP in JSON format is provided in Appendix B.

```
                               WDM-TE-node
        +-----------------------------------------------------------+
        |                                         ROADM             |
        |      Local OT        Splitter     +---------------+       |
        |   +-------------+    +---------+  |               | Line  |
        |   |         TTP|    |     ---o-->o------\        | LTP 1 |
        |   |       +----|    |    /    |  |       \-------o-------o->
      --o-->|       | Tx o--->o---o     |  |               |       |
        |   |       +----|    |    \    |  |               |       |
      <-o---|       | Rx o    |     ---o-->o---\           | Line  |
        |   |       +----|    +---------+  |    \          | LTP 2 |
        |   |            |                 |     \         o-------o->
        |   +-------------+       internal |      \        |       |
        |                         AD ports o       \       |       |
        |                                  |        \      | Line  |
        |                                  |         \     | LTP 3 |
        |                                  |          \---o-------o->
        |                                  o               |       |
        |                                  |               |       |
        |                                  +---------------+       |
        +-----------------------------------------------------------+
```

      Figure 15: OT and OTSi protection function are an integral part
                 of the WDM-TE- node (transmit direction)

```
                                 WDM-TE-node
        +---------------------------------------------------------+
        |      Local OT                                           |
        |   +------------+                      ROADM             |
        |   |            |     Selector    +--------------+       |
        |   |       +----|    +--------+   |              | Line  |
      --o-->|       | Tx o    |     ---o<--o------\       | LPT 1 |
        |   |       +----|    |    /   |   |       \------o-------o<-
      <-o---|       | Rx o<---o---o    |   |              |       |
        |   |       +----|    |    \   |   |              |       |
        |   |         TTP|    |     ---o<--o---\          | Line  |
        |   +------------+    +--------+   |    \         | LTP 2 |
        |                                  |     \        o-------o<-
        |                         internal |      \       |       |
        |                         AD ports o       \      |       |
        |                                  |        \     | Line  |
        |                                  |         \    | LTP 3 |
        |                                  |          \---o-------o<-
        |                                  o              |       |
        |                                  |              |       |
        |                                  +--------------+       |
        +---------------------------------------------------------+
```

Figure 16: OT and OTSI protection function are an integral part of the WDM-TE- node (receive direction)

2.11.1.2. OT and OTSi protection/ROADM functions are in two adjacent WDM-TE-node (remote OT)

This use case is based on the architecture illustrated in Figure 9 where the optical transponder is not part of the WDM-TE-node containing the ROADM function (WDM-TE-node-2) but is part of a separate WDM-TE-node (WDM-TE-node-1) containing one or more optical transponders (remote OTs). WDM-TE-node-2 contains:

* Splitter/selector protection function
* ROADM function

Figure 17 illustrates such a network configuration in the transmit/ forward direction showing the two WDM-TE-nodes where the protection function is the optical splitter in WDM-TE-node-2 and Figure 18 illustrates the same network configuration in the receive/reverse direction where the protection function is the optical selector in WDM-TE-node-2 selecting one of the two incoming OTSi signals and switching to the other incoming OTSi signal when the optical power of the selected OTSi signal drops below a pre-defined threshold.

In the network configuration shown in Figure 17 and Figure 18, respectively, the two WDM-TE-nodes are interconnected via a TE-link carrying a single OTSi signal. This TE-link interconnects the remote OT with an add-drop port of WDM-TE-node-2 and in the following the qualifier "add-drop" is used to refer to that LTP as opposed to the line LTPs representing degrees of WDM-TE-node-2. Like for the protected TTP in Section 2.11.1.1, the optional protection-type leaf is used to indicate whether the add-drop LTP is connected to a protection function and then to two line LTPs via the ROADM function inside WDM-TE-node-2 or whether it is connected to a single line LTP via the ROADM function inside WDM-TE-node-2 (unprotected add-drop LTP). While the protection-type attribute was already defined for the TTP, the YANG model has been augmented to also support this optional attribute for the LTP.

For protected LTPs, the connectivity-matrix has been augmented such that the potential connectivity can now be described between an add-drop LTP and multiple line LTPs including the related optical impairments. Without this new capability, it was only possible to describe the potential connectivity between an add-drop LTP and a single line LTP (unprotected case). If the optical impairments are the same from the protected add-drop LTP to all line LTPs, which is usually the case, the optical impairments should be omitted for the additional LTPs leading to a more compact connectivity matrix description. If the optical impairments are different, however, they can be described for each additional LTP separately.

```
        WDM-TE-node-1                      WDM-TE-node-2
     +----------------+      +---------------------------------------+
     |                |      |                     ROADM             |
     |      Remote OT |      |    Splitter    +--------------+       |
     |   +------------+      |   +--------+   |              | Line  |
     |   |         TTP|      |AD |     ---o-->o------\       | LTP 1 |
     |   |       +----|      |LTP|    /   |   |       \------o-------o->
   --o-->|       | Tx o----->o-->o---o    |   |              |       |
     |   |       +----|      |   |    \   |   |              |       |
   <-o---|       | Rx o      |   |     ---o-->o---\          | Line  |
     |   |       +----|      |   +--------+   |    \         | LTP 2 |
     |   |            |      |                |     \        o-------o->
     |   +------------+      |AD LTP          |      \       |       |
     |                |      o----------------o       \      |       |
     |                |      |                |        \     | Line  |
     |                |      |unprot. AD LTPs |         \    | LTP 3 |
     |                |      |                |          \---o-------o->
     |                |      o----------------o              |       |
     |                |      |AD LTP          |              |       |
     |                |      |                +--------------+       |
     +----------------+      +---------------------------------------+
```

Figure 17: OT and OTSi protection/ROADM functions are in two adjacent WDM-TE- node (remote OT, transmit direction)

```
        WDM-TE-node-1                      WDM-TE-node-2
     +----------------+      +---------------------------------------+
     |      Remote OT |      |                                       |
     |   +------------+      |                     ROADM             |
     |   |            |      |    Selector    +--------------+       |
     |   |       +----|      |   +--------+   |              | Line  |
   --o-->|       | Tx o      |   |     ---o<--o------\       | LTP 1 |
     |   |       +----|      |   |    /   |   |       \------o-------o<-
   <-o---|       | Rx o<-----o<--o---o    |   |              |       |
     |   |       +----|      |AD |    \   |   |              |       |
     |   |         TTP|      |LTP|     ---o<--o---\          | Line  |
     |   +------------+      |   +--------+   |    \         | LTP 2 |
     |                |      |                |     \        o-------o<-
     |                |      |AD LTP          |      \       |       |
     |                |      o----------------o       \      |       |
     |                |      |                |        \     | Line  |
     |                |      |unprot. AD LTPs |         \    | LTP 3 |
     |                |      |                |          \---o-------o<-
     |                |      o----------------o              |       |
     |                |      |AD LTP          |              |       |
     |                |      |                +--------------+       |
     +----------------+      +---------------------------------------+
```

Figure 18: OT and OTSi protection/ROADM functions are in two adjacent WDM-TE- node (remote OT, receive direction)

2.11.1.3. OT and protection function are both in an adjacent WDM-TE-node (protected remote OT)

The use case illustrated in Figure 19 is similar to the use case in Section 2.11.1.1. The difference is that WDM-TE-node-1 does not contain the ROADM function but contains:

* Optical transponder function including the transceiver
* Splitter/selector protection function

WDM-TE-node-1 can be a data center device or a router device that is supporting 1+1 OTSi protection for its OTs while WDM-TE-node-2 is a WDM-TE-node providing add-drop ports for remote OTs as depicted in Figure 9. WDM-TE-node-1 and WDM-TE-node-2 are interconnected via two separate TE-links, each carrying a single OTSi signal. The protection configuration for the protected TTP in WDM-TE-node-1 can be described in the same way as for the use in Section 2.11.1.1 using the local-link-connectivity list.

```
            WDM-TE-node-1                        WDM-TE-node-2
    +-----------------------------+      +---------------------------+
    |      protected              |      |         ROADM             |
    |      remote OT      Splitter|      |    +--------------+       |
    |   +------------+   +--------+      |AD  |              | Line  |
    |   |         TTP|   |     ---o----->o----o------\       | LTP 1 |
    |   |       +----|   |    /LTP|      |LTP |       \------o-------o->
  --o-->|       | Tx o-->o---o    |      |    |              |       |
    |   |       +----|   |    \   |      |AD  |              |       |
  <-o---|       | Rx o   |     ---o----->o----o---\          | Line  |
    |   |       +----|   |     LTP|      |LTP |    \         | LTP 2 |
    |   |            |   +--------+      |    |     \        o-------o->
    |   +------------+            |      |    |      \       |       |
    |                             |      o----o       \      |       |
    |                             |      |AD  |        \     | Line  |
    |                             |      |LTPs|         \    | LTP 3 |
    |                             |      |    |          \---o-------o->
    |                             |      o----o              |       |
    |                             |      |    |              |       |
    |                             |      |    +--------------+       |
    +-----------------------------+      +---------------------------+
```

Figure 19: OT and OTSI protection function are both in an adjacent WDM-TE-node (protected remote OT, transmit direction)

2.11.2. OMS MCG protection

OMS MCG protection is a 1+1 protection architecture where a TE-link representing an OMS MCG between two adjacent WDM-TE-nodes is 1+1 protected. This media layer protection type is also described in Appendix III of [G.873.1_Amd1]. Figure 20 illustrates this 1+1 OMS MCG protection type and shows a 1+1 protected TE-link together with an unprotected TE-link between the same two adjacent WDM-TE-nodes. The protected TE-link in Figure 20 is composed of an underlying primary and secondary TE-link. This modeling approach is described below.

1+1 OMS MCG protection is a local protection scheme, which can be modeled based on TE-link properties already defined in [RFC8795]. The 1+1 protected TE-link is associated with the two underlying TE-links representing the physical links, which are forming the 1+1 protection group together with the splitter and selector functions in the adjacent WDM-TE-nodes as depicted in Figure 20. This modeling approach is described in more detail in Section 2.11.2.1.

Alternatively, it is possible to model the 1+1 OMS MCG protection as single protected TE-link abstracting the two underlying physical links as well as the splitter and selector functions in the two adjacent WDM-TE-nodes. This modeling approach is described in more detail in Section 2.11.2.2.

For both modeling approaches, the splitter and selector functions are not represented as separate entities in the model. Their optical impairments can be included in the optical impairments of the ROADM paths in the two adjacent WDM-TE-nodes (connectivity matrix and LLCL, respectively) or in the optical impairments of the 1+1 protected TE-link abstracting the two underlying physical OMS links.

```
               WDM-TE-node-1                     WDM-TE-node-2
         +-----------------------+         +-----------------------+
         |     ROADM     Splitter|         |Selector     ROADM     |
         |   +-------+   +-------+  prot.  +-------+   +-------+   |
         |   |       |   |    -->o-------->o-->    |   |       |   |
         |   |       |   |   /   |  prim.  |   \   |   |       |   |
         |   |       o-->o--o    |         |    o--o-->o       |   |
         |   |       |   |   \   |  second.|   /   |   |       |   |
         |   |       |   |    -->o-------->o-->    |   |       |   |
         |   |       |   +-------+         +-------+   |       |   |
         |   |       |   Selector| Line 1  |Splitter   |       |   |
         |   |       |   +-------+         +-------+   |       |   |
         |   |       |   |    <--o<--------o<--    |   |       |   |
         |   |       |   |   /   |  prim.  |   \   |   |       |   |
         |   |       o<--o--o    |         |    o--o<--o       |   |
         |   |       |   |   \   |  second.|   /   |   |       |   |
         |   |       |   |    <--o<--------o<--    |   |       |   |
         |   |       |   +-------+ TE-link +-------+   |       |   |
         |   |       |           |         |           |       |   |
         |   |       |           | unprot. |           |       |   |
         |   |       o---------->o-------->o---------->o       |   |
         |   |       |           | Line 2  |           |       |   |
         |   |       o<----------o<--------o<----------o       |   |
         |   |       |           | TE-link |           |       |   |
         |   |       |           |         |           |       |   |
         |   +-------+           |         |           +-------+   |
         |                       |         |                       |
         +-----------------------+         +-----------------------+
```

Figure 20: Two WDM-TE-nodes with a protected and an unprotected OMS MCG (TE- link)

2.11.2.1. OMS MCG Protection Modeled as Protected TE-link with underlying TE-links

This modeling approach models the 1+1 protected TE-link as an additional TE-link entity on top of the primary and secondary TE-link between the two adjacent WDM-TE-nodes terminating the 1+1 OMS MCG protection group formed by these two TE-links and the splitter and selector functions in the two nodes. This 1+1 protected TE-link is associated with underlying primary and secondary TE-links forming the 1+1 protection group. The following "te-link-attributes" already defined in [RFC8795] and [I-D.ietf-teas-rfc8776-update] can be used for modeling the 1+1 protected TE-link ("te-link-attributes") augmentation copied from [RFC8795]:

```
augment /nw:networks/nw:network/nt:link:
+--rw te!
   +--rw te-link-attributes
   |  ....................
   |  +--rw underlay {te-topology-hierarchy}?
   |  |  +--rw enabled?                      boolean
   |  |  +--rw primary-path
   |  |  |  +--rw network-ref?    leafref
   |  |  |     ....................
   |  |  +--rw backup-path* [index]
   |  |  |  +--rw index           uint32
   |  |  |  +--rw network-ref?    leafref
   |  |  |     ....................
   |  ....................
   |  +--rw link-protection-type?          identityref
   |  ....................
```

These attributes are used as follows:

* "underlay": the presence of this container indicates that an underlying protection scheme exists
* "enabled": (boolean) is set to ’true’
* "primary-path": is referencing the primary OMS MCG (TE-link)
* "backup-path": is referencing the secondary OMS MCG (TE-link)
* "link-protection-type" (identityref) set to ’link-protection-1-plus-1’ as defined in [I-D.ietf-teas-rfc8776-update]

The optical impairments for the underlying primary and secondary TE-link can be described as for unprotected TE-links. It MAY also be possible to only describe the optical impairments for the 1+1 protected TE-link. In this case the optical impairments of the worst of the two underlying TE-links shall be used. This should be sufficient as input for path computation (worst case optical feasibility consideration).

```
            WDM-TE-node-1                                 WDM-TE-node-2
       +-----------------------+           +-----------------------+
       |     ROADM     Splitter|           |Selector     ROADM     |
       |   +-------+   +-------+LTP2   LTP4+-------+   +-------+   |
       |   |       |   |    -->o----------->o-->    |   |       |   |
   LTP1|   |    RP1|   |   /   |  prim.    |   \   |   |RP2    |   |LTP6
   --->o-->o.......o-->o--o    |           |    o--o-->o.......o-->o--->
       |   |       |   |   \   |  second.  |   /   |   |       |   |
       |   |       |   |    -->o----------->o-->    |   |       |   |
       |   +-------+   +-------+LTP3   LTP5+-------+   +-------+   |
       |                       |           |                       |
       +-----------------------+           +-----------------------+

                 --+                                   +--
        ROADM port |                                   | ROADM port
               RP1 o---------------------------------->o RP2
                   |                                   |
                 --+                                   +--
                      1+1 protected OMS MCG (TE-link)
                      between ROADM ports RP1 and RP2

                underlying primary and secondary TE-links:

                             --+         +--
                               |  prim.    |
                          LTP2 o----------->o LTP4
                          LTP3 o----------->o LTP5
                               |  second.  |
                             --+         +--

           connectivity matrix provides optical impairments in
           forward direction between LTPs in the two WDM-TE-nodes:
           * LTP1 and LTP2,                     * LTP4 and LTP6,
           * LTP1 and LTP3                      * LTP5 and LTP6
```

Figure 21: Modeling view of 1+1 protected TE-link with underlying primary and secondary TE-link (forward direction)

```
            WDM-TE-node-1                         WDM-TE-node-2
       +-----------------------+           +-----------------------+
       |     ROADM             |           |             ROADM     |
       |   +-------+   +-------+LTP2’ LTP4’+-------+   +-------+   |
       |   |       |   |    <--o<----------o<--    |   |       |   |
   LTP1’   |   RP1’|   |   /   |  prim.    |   \   |   |RP2’   |   LTP6’
   <---o<--o.......o<--o--o    |           |    o--o<--o.......o<--o<---
       |   |       |   |   \   |  second.  |   /   |   |       |   |
       |   |       |   |    <--o<----------o<--    |   |       |   |
       |   +-------+   +-------+LTP3’ LTP5’+-------+   +-------+   |
       |               Selector|           |Splitter               |
       +-----------------------+           +-----------------------+

                 --+                                   +--
        ROADM port |                                   | ROADM port
               RP1’o<----------------------------------o RP2’
                   |                                   |
                 --+                                   +--
                     1+1 protected OMS MCG (TE-link)
                     between ROADM ports RP1’ and RP2’

                underlying primary and secondary TE-links:

                             --+           +--
                               |  prim.    |
                          LTP2’o<----------o LTP4’
                          LTP3’o<----------o LTP5’
                               |  second.  |
                             --+           +--

           connectivity matrix provides optical impairments in
           reverse direction between LTPs in the two WDM-TE-nodes:
           * LTP2’ and LTP1’,                   * LTP6’ and LTP4’,
           * LTP3’ and LTP1’                    * LTP6’ and LTP5’
```

Figure 22: Modeling view of 1+1 protected TE-link with underlying primary and secondary TE-link (reverse direction)

Figure 21 and Figure 22 illustrate this modeling approach including the LTPs in WDM-TE-node-1 and WDM-TE-node-2, respectively. In addition to the physical view, the following TE-links are shown in the two directions:

* The 1+1 protected TE-link

* The underlying primary TE-link
* The underlying secondary TE-link

The optical impairments of the splitter (outgoing direction) and the selector (incoming direction) are included in the optical impairments described by the connectivity matrix and the local link connectivity list for the TE node. For the example shown in Figure 21 in the forward direction, the connectivity matrix describes the optical impairments between LPT1 and LTP2 as well as LTP1 and LTP3 for WDM-TE-node-1. Likewise, the connectivity matrix describes the optical impairments between LPT4 and LTP6 as well as LTP5 and LTP6 in WDM-TE-node-2. The same applies to the corresponding LTPs in the reverse direction.

2.11.2.2. OMS MCG Protection Modeled as Single Protected TE-link

This modeling approach abstracts the two physical OMS links carrying the same OMS MCG together with the splitter and selector functions in the two WDM-TE-nodes forming the OMS protection group into a single TE-link. When this modeling approach is used the "te-link-attributes" already defined in [RFC8795] and [I-D.ietf-teas-rfc8776-update] are used as follows:

```
 augment /nw:networks/nw:network/nt:link:
  +--rw te!
     +--rw te-link-attributes
     |  ....................
     |  +--rw link-protection-type?          identityref
     |  ....................
```

* "underlay": this container MUST NOT be present
* "link-protection-type" (identityref) set to 'link-protection-1-plus-1' as defined in [I-D.ietf-teas-rfc8776-update]

The optical impairments exposed for this 1+1 protected TE-link are typically based on the optical impairments of the worse of the two underlying physical OMS links including the optical impairments imposed by the splitter (outgoing direction) and selector (incoming direction).

Figure 23 and Figure 24 illustrate this modeling approach where the splitter/selector in the adjacent WDM-TE-nodes, WDM-TE-node-1 and WDM-TE-node-2, as well as the two physical OMS MCG links are abstracted into a single 1+1 protected TE-link. This is illustrated by the dotted line surrounding these four physical entities in Figure 23 and Figure 24, respectively. Based on this modeling approach, the ROADM port connected to the splitter/selector function is modeled as LTP for the 1+1 protected TE-link (LTP2 in WDM-TE-node-1 and LTP3 in WDM-TE-node-2). In this example, the connectivity matrix describes the optical impairments between LPT1 and LTP2 in WDM-TE-node-1. Likewise, the connectivity matrix describes the optical impairments between LPT3 and LTP4 in WDM-TE-node-2.

```
         WDM-TE-node-1                          WDM-TE-node-2
       +-----------------------+           +-----------------------+
       |     ROADM     Splitter|           |Selector     ROADM     |
       |   +-------+   +.......+...........+.......+   +-------+   |
       |   |       |   .    -->o----------->o-->    .   |       |   |
   LTP1|   |   LTP2|   .   /   |           |   \   .   |LTP3   |   |LTP4
   --->o-->o.......o-->o--o    |           |    o--o-->o.......o-->o--->
       |   |       |   .   \   |           |   /   .   |       |   |
       |   |       |   .    -->o----------->o-->    .   |       |   |
       |   +-------+   +...................+.......+   +-------+   |
       |                       |           |                       |
       +-----------------------+           +-----------------------+

                 --+                                   +--
        ROADM port |                                   | ROADM port
              LTP2 o---------------------------------->o LTP3
                   |                                   |
                 --+                                   +---
                     Splitter/Selector abstracted into
                     1+1 protected OMS MCG (TE-link)

           connectivity matrix provides optical impairments in
           forward direction between LTPs in the two WDM-TE-nodes:
           * LTP1 and LTP2                      * LTP3 and LTP4
```

Figure 23: Modeling view of abstracted 1+1 protected TE-link (forward direction) - ROADM ports modeled as LTPs

```
            WDM-TE-node-1                      WDM-TE-node-2
       +-----------------------+           +-----------------------+
       |     ROADM             |           |            ROADM      |
       |   +-------+   +.......+...........+.......+   +-------+   |
       |   |       |   .    <--o<----------o<--    .   |       |   |
   LTP1'   |  LTP2'|   .   /   |           |   \   .   |LTP3'  |   LTP4'
   <---o<--o.......o<--o--o    |           |    o--o<--o.......o<--o<---
       |   |       |   .   \   |           |   /   .   |       |   |
       |   |       |   .    <--o<----------o<--    .   |       |   |
       |   +-------+   +...................+.......+   +-------+   |
       |               Selector|           |Splitter               |
       +-----------------------+           +-----------------------+

                 --+                                   +--
        ROADM port |                                   | ROADM port
              LTP2 o<----------------------------------o LTP3
                   |                                   |
                 --+                                   +---
                     Splitter/Selector abstracted into
                     1+1 protected OMS MCG (TE-link)

           connectivity matrix provides optical impairments in
           reverse direction between LTPs in the two WDM-TE-nodes:
           * LTP2' and LTP1'                    * LTP4' and LTP3'
```

Figure 24: Modeling view of abstracted 1+1 protected TE-link (reverse direction) - ROADM ports modeled as LTPs

Alternatively, the optical impairments imposed by the splitter and selector in each of the two adjacent WDM-TE-nodes can also be included in the optical impairments described by the connectivity matrix of the two nodes instead of taking them into account as optical impairments of the 1+1 protected TE-link. This is illustrated in Figure 25 in forward direction and Figure 26 in reverse direction below. In this case, the two physical ports on both ends of the 1+1 protected TE-link are abstracted into a single LTP, LTP2 and LTP3, in forward direction and LTP3' and LTP2' in reverse direction.

```
             WDM-TE-node-1                         WDM-TE-node-2
          +-----------------------+           +-----------------------+
          |     ROADM     Splitter|           |Selector     ROADM     |
          |   +-------+   +-------+...........+-------+   +-------+   |
          |   |       |   |    -->o----------->o-->    |   |       |   |
      LTP1|   |       |   |   /   |LTP2   LTP3|   \   |   |       |   |LTP4
      --->o-->o.......o-->o--o    |           |    o--o-->o.......o-->o--->
          |   |       |   |   \   |LTP2   LTP3|   /   |   |       |   |
          |   |       |   |    -->o----------->o-->    |   |       |   |
          |   +-------+   +-------+...........+-------+   +-------+   |
          |                       |           |                       |
          +-----------------------+           +-----------------------+

                               --+           +--
                                 |           |
                            LTP2 o---------->o LTP3
                                 |           |
                               --+           +--
                                 1+1 protected
                                 OMS MCG (TE-link)

           connectivity matrix provides optical impairments in
           forward direction between LTPs in the two WDM-TE-nodes:
           * LTP1 and LTP2                     * LTP3 and LTP4
```

Figure 25: Modeling view of abstracted 1+1 protected TE-link
(forward direction) - physical ports abstracted into single LTP
on both link ends

```
            WDM-TE-node-1                          WDM-TE-node-2
       +-----------------------+           +-----------------------+
       |     ROADM             |           |             ROADM     |
       |   +-------+   +-------+...........+-------+   +-------+   |
       |   |       |   |    <--o<----------o<--    |   |       |   |
   LTP1’   |       |   |   /   |LTP2’ LTP3’|   \   |   |       |   LTP4’
   <---o<--o.......o<--o--o    |           |    o--o<--o.......o<--o<---
       |   |       |   |   \   |LTP2’ LTP3’|   /   |   |       |   |
       |   |       |   |    <--o<----------o<--    |   |       |   |
       |   +-------+   +-------+...........+-------+   +-------+   |
       |               Selector|           |Splitter               |
       +-----------------------+           +-----------------------+

                             --+           +--
                               |           |
                          LTP2’o<----------o LTP3’
                               |           |
                             --+           +--
                               1+1 protected
                               OMS MCG (TE-link)

           connectivity matrix provides optical impairments in
           reverse direction between LTPs in the two WDM-TE-nodes:
           * LTP2’ and LTP1’                    * LTP4’ and LTP3’
```

Figure 26: Modeling view of abstracted 1+1 protected TE-link (reverse direction) - physical ports abstracted into single LTP on both link ends

3. Optical Impairment Topology YANG Model

```
<CODE BEGINS> file "ietf-optical-impairment-topology@2026-02-26.yang"
module ietf-optical-impairment-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml"
          + ":ns:yang:ietf-optical-impairment-topology";
  prefix oit;

  import ietf-network {
    prefix nw;
    reference
      "RFC 8345: A YANG Data Model for Network Topologies";
  }
  import ietf-network-topology {
    prefix nt;
    reference
      "RFC 8345: A YANG Data Model for Network Topologies";
```

```
     }
     import ietf-te-topology {
       prefix tet;
       reference
         "RFC 8795: YANG Data Model for Traffic Engineering (TE)
                    Topologies";
     }
     import ietf-te-types {
       prefix te-types;
       reference
         "RFC YYYY: Updated Common YANG Data Types for Traffic
                    Engineering";
     }

     /* Note: The RFC Editor will replace YYYY with the number assigned
        to the RFC once draft-ietf-teas-rfc8776-update becomes an RFC.*/

     import ietf-layer0-types {
       prefix l0-types;
       reference
         "RFC ZZZZ: A YANG Data Model for Layer 0 Types";
     }

     /* Note: The RFC Editor will replace ZZZZ with the number assigned
        to the RFC once draft-ietf-ccamp-rfc9093-bis becomes an RFC.*/

     organization
       "IETF CCAMP Working Group";
     contact
       "WG Web: <https://datatracker.ietf.org/wg/ccamp/>
        WG List: <mailto:ccamp@ietf.org>

        Editor:   Gabriele Galimberti <gabriele.galimberti@nokia.com>
        Editor:   Le Rouzic Esther <esther.lerouzic@orange.com>
        Editor:   Julien Meuric <julien.meuric@orange.com>
        Editor:   Italo Busi <Italo.Busi@huawei.com>
        Editor:   Dieter Beller <dieter.beller@nokia.com>
        Editor:   Sergio Belotti <Sergio.belotti@nokia.com>
        Editor:   Griseri Enrico <enrico.griseri@nokia.com>
        Editor:   Roberto Manzotti <rmanzott@cisco.com>
        Editor:   Gert Grammel <ggrammel@juniper.net>";
     description
       "This module contains a collection of YANG definitions for
        impairment-aware optical networks.

        Copyright (c) 2026 IETF Trust and the persons identified as
        authors of the code.  All rights reserved.
```

```
        Redistribution and use in source and binary forms, with or
        without modification, is permitted pursuant to, and subject
        to the license terms contained in, the Revised BSD
        License set forth in Section 4.c of the IETF Trust's Legal
        Provisions Relating to IETF Documents
        (https://trustee.ietf.org/license-info).

        All revisions of IETF and IANA published modules can be found
        at the YANG Parameters registry group
        (https://www.iana.org/assignments/yang-parameters).

        The key words 'MUST', 'MUST NOT', 'REQUIRED', 'SHALL', 'SHALL
        NOT', 'SHOULD', 'SHOULD NOT', 'RECOMMENDED', 'NOT RECOMMENDED',
        'MAY', and 'OPTIONAL' in this document are to be interpreted as
        described in BCP 14 (RFC 2119) (RFC 8174) when, and only when,
        they appear in all capitals, as shown here.

        This version of this YANG module is part of RFC XXXX; see
        the RFC itself for full legal notices.";

     // RFC Ed.: replace XXXX with actual RFC number and remove
     // this note
     // replace the revision date with the module publication date
     // the format is (year-month-day)

     revision 2026-02-26 {
       description
         "Initial version.";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware
                    Optical Networks";
     }

     /*
      * Identities
      */

     identity otsi-protection {
       base te-types:lsp-protection-type;
       description
         "Individual OTSi(G) protection LSP protection type.";
       reference
         "ITU-T G.873.1 v5.2 (02/2022): Optical transport network:
                        Linear protection, Appendix III";
     }

     /*
      * Groupings
```

```
      */

     grouping amplifier-params {
       description
         "Describes parameters for an amplifier.";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware
                    Optical Networks, Section 2.4";
       container amplifier {
         description
           "The attributes of an amplifier.";
         leaf type-variety {
           type string;
           mandatory true;
           description
             "The type of the amplifier.

              It is usually a vendor-specific string referencing
              specification in a separate equipment catalog.";
         }
         container operational {
           description
             "Amplifier operational parameters.";
           list amplifier-element {
             key "frequency-range-id stage-order";
             description
               "The list of parallel amplifier elements within an
                amplifier used to amplify different frequency ranges.

                Two elements in the list MUST NOT have the same range
                or overlapping ranges.";
             uses l0-types:frequency-range-with-identifier;
             leaf stage-order {
               type uint8;
               description
                 "It allows defining for each spectrum bandwidth the
                  cascade order of each amplifier-element.";
             }
             leaf name {
               type string;
               description
                 "The name of the amplifier element as specified in
                  the vendor’s specification associated with the
                  type-variety.";
             }
             leaf type-variety {
               type string;
               description
```

```
              "The type of the amplifier element.

               It is usually a vendor-specific string referencing
               specification in a separate equipment catalog.

               This attribute applies only when the type-variety of
               the amplifier is not sufficient to describe the
               amplifier element type.";
          }
          container power-param {
            description
              "Amplifier elements typically equalize the optical
               power across the amplified channels using one of the
               available equalization strategies - either targeting
               a specific output power, or a specific power spectral
               density (PSD), after the out-voa.";
            choice power-param {
              mandatory true;
              description
                "Select the mode: channel power or power spectral
                 density (PSD).";
              case channel-power {
                leaf nominal-carrier-power {
                  type l0-types:power-dbm-or-unknown;
                  mandatory true;
                  description
                    "Reference channel power.";
                }
              }
              case power-spectral-density {
                leaf nominal-psd {
                  type l0-types:psd-or-unknown;
                  mandatory true;
                  description
                    "Reference power spectral density (PSD).";
                }
              }
            }
          } // container power-param
          leaf pdl {
            type l0-types:power-loss-or-unknown;
            description
              "Polarization Dependent Loss (PDL).";
            reference
              "ITU-T G.671 v9.0 (11/2025): Transmission
                           characteristics of optical components and
                           subsystems, clause 3.2.2.35
               ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for
```

```
                                optical fibre submarine cable systems,
                                clause 8.1.5.2.2";
             }
             choice amplifier-element-type {
               mandatory true;
               description
                 "Identifies whether the amplifier element is an
                  Optical Amplifier (OA) or a Dynamic Gain Equalizer
                  (DGE).";
               container optical-amplifier {
                 description
                   "The attributes applicable only to amplifier
                    elements.";
                 leaf actual-gain {
                   type l0-types:power-gain-or-unknown;
                   mandatory true;
                   description
                     "The value of the gain provided by the
                      amplification stage of the optical amplifier.";
                 }
                 leaf in-voa {
                   type l0-types:power-loss-or-unknown;
                   description
                     "Loss introduced by the Variable Optical Attenuator
                      (VOA) at the input of the amplification stage of
                      the amplifier, if present.";
                 }
                 leaf out-voa {
                   type l0-types:power-loss-or-unknown;
                   description
                     "Loss introduced by the Variable Optical Attenuator
                      (VOA) at the output of the amplification stage of
                      the amplifier, if present.";
                 }
                 leaf tilt-target {
                   type l0-types:decimal-2-or-unknown;
                   units "dB";
                   mandatory true;
                   description
                     "The tilt target defined between lower and upper
                      frequency of the amplifier frequency range.";
                 }
                 leaf total-output-power {
                   type l0-types:power-dbm-or-unknown;
                   mandatory true;
                   description
                     "It represents the total output power measured in
                      the range specified by the frequency-range.
```

```
                     Optical power is especially needed to
                     re-compute/check consistency of span
                     (fiber + concentrated loss) loss value, with
                     respect to loss/gain information on elements.";
                }
                leaf raman-direction {
                  type enumeration {
                    enum co-propagating {
                      description
                        "Co-propagating indicates that optical pump
                         light is injected in the same direction to the
                         optical signal that is amplified
                         (forward pump).";
                    }
                    enum counter-propagating {
                      description
                        "Counter-propagating indicates that optical
                         pump light is injected in opposite direction
                         to the optical signal that is amplified
                         (backward pump).";
                    }
                  }
                  description
                    "The direction of injection of the raman pump.";
                }
                list raman-pump {
                  key "pump-id";
                  description
                    "The list of pumps for the Raman amplifier.";
                  leaf pump-id {
                    type uint16;
                    description
                      "The identifier of a pump within an amplifier
                       element.";
                  }
                  leaf frequency {
                    type l0-types:frequency-thz;
                    description
                      "The raman pump central frequency.";
                  }
                  leaf power {
                    type l0-types:decimal-2-or-unknown;
                    units "Watts";
                    description
                      "The total pump power considering a depolarized
                       pump at the raman pump central frequency.";
                  }
                }
```

```
               } // container optical-amplifier
               container dynamic-gain-equalizer {
                 presence
                   "When present it indicates that the amplifier element
                    is a Dynamic Gain Equalizer (DGE).";
                 description
                   "The attributes applicable only to DEG amplifier
                    elements.";
                 list media-channel {
                   key "flexi-n";
                   description
                     "List of media channels represented as (n,m).";
                   uses l0-types:flexi-grid-frequency-slot {
                     refine "flexi-m" {
                       mandatory true;
                     }
                   }
                   leaf delta-power {
                     type l0-types:power-ratio-or-unknown;
                     description
                       "Deviation of the carrier power with respect to
                        the reference carrier power, to account for
                        power offset related to the carrier signal
                        spectrum width or baud rate.";
                   }
                 } // media channels list
               } // container dynamic-gain-equalizer
             } // choice amplifier-element-type
           } // list amplifier-element
         } // container operational
       } // container amplifier
     } // grouping amplifier-params

     grouping fiber-params {
       description
         "String identifier of fiber type referencing a
          specification in a separate equipment catalog.";
       container fiber {
         description
           "Fiber characteristics.";
         reference
           "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                      Networks, Section 2.9";
         leaf type-variety {
           type string;
           mandatory true;
           description
             "The type of the fiber.
```

```
              It can be a string referencing a standard document (e.g.,
              ITU-T G.652) or a vendor-specific string referencing
              specification in a separate equipment catalog.";
         }
         leaf length {
           type l0-types:decimal-2-or-unknown;
           units "km";
           mandatory true;
           description
             "Length of fiber.";
         }
         leaf loss-coef {
           type l0-types:decimal-2-or-unknown;
           units "dB/km";
           mandatory true;
           description
             "Loss coefficient of the fiber.";
         }
         leaf total-loss {
           type l0-types:power-loss-or-unknown;
           config false;
           description
             "The measured total loss of the fiber, which includes
              all possible losses: fiber loss and conn-in and conn-out
              losses.

              This attribute is not present when the total loss cannot
              be measured.";
         }
         leaf pmd {
           type l0-types:decimal-2-or-unknown;
           units "ps";
           description
             "Polarization Mode Dispersion (PMD) of the fiber.";
           reference
             "ITU-T G.671 v9.0 (11/2025): Transmission characteristics
                          of optical components and subsystems,
                          clause 3.2.2.37
              ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for
                            optical fibre submarine cable systems,
                            clause 6.2.2.3";
         }
         leaf conn-in {
           type l0-types:power-loss-or-unknown;
           description
             "The loss of the connector at the input of the fiber.";
         }
         leaf conn-out {
```

```
           type l0-types:power-loss-or-unknown;
           description
             "The loss of the connector at the output of the fiber.";
         }
       }
     }

     grouping roadm-common-path {
       description
         "The optical impairments of a ROADM which are common to all
          its paths (express path, add path or drop path).";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                    Networks, Section 2.10.4";
       leaf roadm-pmd {
         type union {
           type decimal64 {
             fraction-digits 8;
             range "0..max";
           }
           type l0-types:unknown-value;
         }
         units "ps";
         description
           "Polarization Mode Dispersion (PMD).";
         reference
           "ITU-T G.671 v9.0 (11/2025): Transmission characteristics of
                        optical components and subsystems,
                        clause 3.2.2.37
            ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems,
                          clause 6.2.2.3";
       }
       leaf roadm-cd {
         type l0-types:decimal-5-or-unknown;
         units "ps/nm";
         description
           "Chromatic Dispersion (CD).";
         reference
           "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems,
                          clause 6.2.2.4";
       }
       leaf roadm-pdl {
         type l0-types:power-loss-or-unknown;
         description
           "Polarization Dependent Loss (PDL).";
         reference
```

```
           "ITU-T G.671 v9.0 (11/2025): Transmission characteristics of
                        optical components and subsystems,
                        clause 3.2.2.35
            ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems,
                          clause 8.1.5.2.2";
       }
       leaf roadm-inband-crosstalk {
         type l0-types:decimal-2-or-unknown;
         units "dB";
         description
           "One of the basic properties of the key optical device
            wavelength selective switch (WSS) is the isolation (i.e.,
            the ratio between the optical power of a selected optical
            channel and the leakage power of unselected channels).

            In the presence of imperfect isolation, the originated
            leakage signals, usually known as crosstalk signals, will
            interfere with the primary signal at the receiver end,
            contributing to degrade the signal quality.
            This interference is particularly harmful when both the
            signal and interference have the same nominal wavelength
            leading to the in-band crosstalk.";
         reference
           "ISSN 1068-5200: A framework for analyzing in-band crosstalk
                            accumulation in ROADM-based optical
                            networks";
       }
       leaf roadm-maxloss {
         type l0-types:power-loss-or-unknown;
         description
           "This is the maximum expected path loss from the
            ROADM ingress to the ROADM egress
            assuming no additional path loss is added.";
       }
     } // grouping roadm-common-path

     grouping roadm-add-path {
       description
         "The optical impairments of a ROADM add path.";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                    Networks, Section 2.10.4";
       uses roadm-common-path {
         refine "roadm-inband-crosstalk" {
           description
             "In-band crosstalk, or coherent crosstalk,
              can occur in components that can have multiple same
```

```
              wavelength inputs,with the inputs either
              routed to different output ports,
              or all but one blocked.

              In the case of add path it is the total
              of the add block + egress WSS crosstalk contributions.";
         }
         refine "roadm-maxloss" {
           description
             "This is the maximum expected add path loss from
              the add/drop port input to the ROADM egress,
              assuming no additional add path loss is added.

              This is used to establish the minimum required
              transponder output power required to hit the ROADM
              egress target power levels and preventing to hit
              the WSS attenuation limits.

              If the add path contains an internal amplifier
              this loss value MUST be based on worst case expected
              amplifier gain due to ripple or gain uncertainty.";
         }
       }
       leaf roadm-pmax {
         type l0-types:power-dbm-or-unknown;
         description
           "This is the maximum (per carrier) power level
            permitted at the add block input ports,
            that can be handled by the ROADM node.

            This can reflect either add amplifier power
            constraints or WSS adjustment limits.

            Higher power transponders would need to have
            their launch power reduced to this value or lower.";
       }
       leaf roadm-osnr {
         type l0-types:snr-or-unknown;
         description
           "Optical Signal-to-Noise Ratio (OSNR).

            If the add path contains the ability to adjust the
            carrier power levels into an add path amplifier
            (if present) to a target value,
            this reflects the OSNR contribution of the
            add amplifier assuming this target value is obtained.

            The worst case OSNR based on the input power and
```

```
            NF calculation method, and this value, MUST be used
            (if both are defined).";
         reference
           "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems, clause 8.1.3";
       }
       leaf roadm-noise-figure {
         type l0-types:decimal-5-or-unknown;
         units "dB";
         description
           "Noise Figure. If the add path contains an amplifier,
            this is the noise figure of that amplifier inferred
            to the add port.
            This permits add path OSNR calculation based
            on the input power levels to the add block
            without knowing the ROADM path losses to
            the add amplifier.";
         reference
           "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems, clause 8.1.3";
       }
     } // grouping roadm-add-path

     grouping roadm-drop-path {
       description
         "The optical impairments of a ROADM drop path.";
       uses roadm-common-path {
         refine "roadm-inband-crosstalk" {
           description
             "In-band crosstalk, or coherent crosstalk, can occur in
              components that can have multiple same wavelength
              inputs,with the inputs either routed to different
              output ports,or all but one blocked.

              In the case of drop path it is the total
              of the ingress to drop, e.g. WSS and drop block
              crosstalk contributions.";
         }
         refine "roadm-maxloss" {
           description
             "The net loss from the ROADM input,to the output
              of the drop block.

              If this ROADM ingress-to-drop path includes an amplifier,
              the amplifier gain reduces the net loss.
              This is before any additional drop path attenuation
              that may be required due to drop amplifier power
              constraints.
```

```
              The max value corresponds to the worst case expected
              loss, including amplifier gain ripple or uncertainty.
              It is the maximum output power of the drop amplifier.";
          }
        }
        leaf roadm-minloss {
          type l0-types:power-loss-or-unknown;
          description
            "The net loss from the ROADM input, to the
             output of the drop block.

             If this ROADM ingress-to-drop path includes
             an amplifier,the amplifier gain reduces the net loss.
             This is before any additional drop path attenuation
             that may be required due to drop amplifier power
             constraints.

             The min value correspond to best case expected loss,
             including amplifier gain ripple or uncertainty.";
        }
        leaf roadm-typloss {
          type l0-types:power-loss-or-unknown;
          description
            "The net loss from the ROADM input, to the output
             of the drop block.

             If this ROADM ingress-to-drop path includes an amplifier,
             the amplifier gain reduces the net loss.

             This is before any additional drop path attenuation
             that may be required due to drop amplifier power
             constraints.

             The typ value correspond to typical case expected loss.";
        }
        leaf roadm-pmin {
          type l0-types:power-dbm-or-unknown;
          description
            "If the drop path has additional loss that is added, for
             example, to hit target power levels into a drop path
             amplifier, or simply, to reduce the power of a strong
             carrier (due to ripple, for example), then the use of the
             ROADM input power levels and the above drop losses is
             not appropriate.

             This parameter corresponds to the minimum value of the Drop
             Channel output power range.";
          reference
```

```
            "ITU-T G.680 v1.0 (07/2007): Physical transfer functions of
                         optical network elements, Table 8-6";
        }
        leaf roadm-pmax {
          type l0-types:power-dbm-or-unknown;
          description
            "If the drop path has additional loss that is added, for
             example, to hit target power levels into a drop path
             amplifier, or simply ,to reduce the power of a strong
             carrier (due to ripple, for example), then the use of the
             ROADM input power levels and the above drop losses is
             not appropriate.

             This parameter corresponds to the maximum value of the Drop
             Channel output power range.";
          reference
            "ITU-T G.680 v1.0 (07/2007): Physical transfer functions of
                         optical network elements, table 8-6";
        }
        leaf roadm-ptyp {
          type l0-types:power-dbm-or-unknown;
          description
            "If the drop path has additional loss that is added,
             for example, to hit target power levels into a
             drop path amplifier,or simply,to reduce the
             power of a strong carrier(due to ripple, for example),
             then the use of the ROADM input power levels and
             the above drop losses is not appropriate.

             This parameter corresponds to the typical case
             per carrier power levels expected at the output
             of the drop block.";
        }
        leaf roadm-osnr {
          type l0-types:snr-or-unknown;
          description
            "Optical Signal-to-Noise Ratio (OSNR).

             Expected OSNR contribution of the drop path
             amplifier (if present) for the case of additional drop
             path loss (before this amplifier) in order to hit
             a target power level (per carrier).

             If both, the OSNR based on the ROADM
             input power level
             (Pcarrier =
             Pref+10Log(carrier-baudrate/ref-baud) + delta-power)
             and the input inferred NF(NF.drop),
```

```
             and this OSNR value, are defined,
             the minimum value between these two MUST be used.";
          reference
            "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                           fibre submarine cable systems, clause 8.1.3";
        }
        leaf roadm-noise-figure {
          type l0-types:decimal-5-or-unknown;
          units "dB";
          description
            "Drop path Noise Figure.

             If the drop path contains an amplifier, this is the noise
             figure of that amplifier, inferred to the ROADM ingress
             port.

             This permits to determine amplifier OSNR contribution
             without having to specify the ROADM node's losses to
             that amplifier.

             This applies for the case of no additional drop path loss,
             before the amplifier, in order to reduce the power
             of the carriers to a target value.";
          reference
            "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                           fibre submarine cable systems, clause 8.1.3";
        }
      } // grouping roadm-drop-path

      grouping concentrated-loss-params {
        description
          "Concentrated loss";
        container concentrated-loss {
          description
            "Concentrated loss";
          reference
            "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                       Networks, section 2.3";
          leaf loss {
            type l0-types:power-loss-or-unknown;
            mandatory true;
            description
              "Loss introduced by the concentrated loss element (e.g., a
               fiber connector, a fiber splice).";
          }
        }
      }
```

```
     grouping oms-general-optical-params {
       description
         "The optical paramaters of an OMS link.";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                    Networks, Section 2.3";
       leaf generalized-snr {
         type l0-types:snr;
         description
           "Generalized SNR.";
         reference
           "ITU-T G.Sup41 v5.0 (07/2024): Design guidelines for optical
                          fibre submarine cable systems, clause 8.1.4";
       }
       leaf equalization-mode {
         type identityref {
           base l0-types:type-power-mode;
         }
         description
           "The equalization mode.

            ROADMs typically equalize the optical power across the
            channels on the OMS using one of the available equalization
            strategies - either targeting a specific output power, or a
            specific power spectral density (PSD).

            When not present it indicates that the information about
            the equalization mode is not reported.

            Reporting this value is needed to support optical
            impairments applications.";
       }
       container power-param {
         description
           "Optical channel power or power spectral densitity (PSD)
            after the ROADM.";
         leaf nominal-carrier-power {
           when "derived-from-or-self(../../equalization-mode, "
              + "'l0-types:carrier-power')";
           type l0-types:power-dbm-or-unknown;
           description
             "Reference channel power.";
         }
         leaf nominal-psd {
           when "derived-from-or-self(../../equalization-mode, "
              + "'l0-types:power-spectral-density')";
           type l0-types:psd-or-unknown;
           description
```

```
              "Reference power spectral density (PSD).";
          }
        } // container power-param
      } // grouping oms-general-optical-params

      grouping otsi-group {
        description
          "The list of the OTSis contained in one OTSiG.";
        reference
          "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                     Networks, Sections 2.3.1 and 2.3.2";
        list otsi {
          key "carrier-id";
          description
            "The list of the OTSis contained in one OTSiG.
             The list could also be of only one element.";
          leaf carrier-id {
            type uint16;
            description
              "The identifier of the OTSi within the OTSiG.";
          }
          leaf carrier-frequency {
            type union {
              type l0-types:frequency-thz;
              type l0-types:unknown-value;
            }
            description
              "OTSi carrier frequency, equivalent to the
               actual configured transmitter frequency.";
          }
          leaf-list e2e-mc-path-id {
            type uint16;
            description
              "The list of the possible end-to-end Media Channel
               (e2e-MC) paths associated with the OTSi which have
               different optical impairments.

               This list is meaningful in case the OTSi can be associated
               with multiple end-to-end Media Channel (e2e-MC) paths
               (e.g., when OPS protection is configured).

               The list can be empty when the OTSi has only one
               e2e-MC path.";
            reference
              "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                         Networks, Section 2.11.1";
          }
        } // OTSi list
```

```
     } // OTSiG grouping

     grouping media-channel-groups {
       description
         "The list of media channel groups (MCGs) and of their
          constituent media channels (MCs).

          This grouping is not intended to be reused outside of this
          module.";
       reference
         "RFC XXXX: A YANG Data Model for Impairment-aware Optical
                    Networks, Sections 2.3.3 and 2.3.4";
       container media-channel-groups {
         presence
           "When present, it indicates that the list media channel
            groups is reported.";
         description
           "The top level container for the list of media channel
            groups.";
         list media-channel-group {
           key "otsi-group-ref";
           description
             "The list of media channel groups";
           leaf otsi-group-ref {
             type leafref {
               path "../../../../../../../otsis/"
                  + "otsi-group/otsi-group-id";
             }
             description
               "Reference to the OTSiG to which the OTSis carried by
                this media channel group belong to.";
           }
           list media-channel {
             key "media-channel-id";
             unique "flexi-n";
             description
               "The list of media channels within the media channel
                group.";
             leaf media-channel-id {
               type int16;
               description
                 "The identifier of media channel within media channel
                  group.

                  It may be equal to the flexi-n attribute, when the
                  flexi-n attribute is present.";
             }
             uses l0-types:flexi-grid-frequency-slot;
```

```
            list otsi-ref {
              key "carrier-ref";
              description
                "The list of references to the OTSis and their
                 end-to-end Media Channel (e2e-MC) paths within the
                 OTSiG carried by this media channel.";
              leaf carrier-ref {
                type leafref {
                  path "../../../../../../../../../otsis/"
                     + "otsi-group[otsi-group-id=current()"
                     + "/../../../otsi-group-ref]/"
                     + "otsi/carrier-id";
                }
                description
                  "Reference to the OTSi within the OTSiG carried
                   by this media channel.";
              }
              leaf-list e2e-mc-path-ref {
                type leafref {
                  path "../../../../../../../../../otsis/"
                     + "otsi-group[otsi-group-id=current()"
                     + "/../../../otsi-group-ref]/"
                     + "otsi[carrier-id=current()"
                     + "/../carrier-ref]/e2e-mc-path-id";
                }
                description
                  "References to the end-to-end Media Channel (e2e-MC)
                   paths of this OTSi which are routed through this
                   media channel.";
              }
            }
            leaf delta-power {
              type l0-types:power-ratio-or-unknown;
              description
                "Deviation from the reference carrier power defined
                 for the OMS.";
            }
          } // media channels list
        } // media-channel-groups list
      }
    } // media media-channel-groups grouping

    grouping oms-element {
      description
        "The list of the OMS elements, i.e., the building blocks
         (e.g., fibers, amplifiers, concentrated loss) that compose the
         OMS between its link termination points.";
      container oms-elements {
```

```
         presence
           "When present, it indicates that the list of OMS elements
            is reported.";
         description
           "The top level container for the list of OMS elements.";
         list oms-element {
           key "elt-index";
           description
             "The list of OMS elements.";
           leaf elt-index {
             type uint16;
             description
               "An index allowing sorting the elements in their physical
                order along the link without constraining their position
                in the list.";
           }
           leaf oms-element-uid {
             type union {
               type string;
               type l0-types:unknown-value;
             }
             description
               "Unique identifier of the OMS element, when known.";
           }
           container reverse-element-ref {
             description
               "It contains references to the elements which are
                associated with this element in the reverse
                direction.";
             leaf link-ref {
               type leafref {
                 path "../../../../../../../../nt:link/nt:link-id";
               }
               description
                 "The reference to the OMS link which the OMS elements
                  belongs to.";
             }
             leaf-list oms-element-ref {
               type leafref {
                 path "../../../../../../../../nt:link[nt:link-id="
                    + "current()/../link-ref]/tet:te/"
                    + "tet:te-link-attributes/oms-attributes/"
                    + "oms-elements/oms-element/elt-index";
               }
               description
                 "The references to the OMS elements.";
             }
           }
```

```
           choice element {
             mandatory true;
             description
               "OMS element type";
             case amplifier {
               uses tet:geolocation-container;
               uses amplifier-params;
             }
             case fiber {
               uses fiber-params;
             }
             case concentrated-loss {
               uses concentrated-loss-params;
             }
           }
         }
       }
     }

     grouping otsi-ref {
       description
         "References to an OTSi.

          This grouping is intended to be reused within the
          transceiver’s list only.";
       leaf otsi-group-ref {
         type leafref {
           path "../../../../../../otsis/otsi-group/"
              + "otsi-group-id";
         }
         description
           "The OTSiG the referenced OTSi belongs to.";
       }
       leaf otsi-ref {
         type leafref {
           path "../../../../../../otsis/otsi-group"
              + "[otsi-group-id=current()/../otsi-group-ref]/otsi/"
              + "carrier-id";
         }
         description
           "The referenced OTSi.";
       }
     }

     /*
      * Data nodes
      */
```

```
     augment "/nw:networks/nw:network/nw:network-types"
           + "/tet:te-topology" {
       description
         "optical-impairment topology augmented";
       container optical-impairment-topology {
         presence
           "Indicates an impairment-aware topology of optical networks";
         description
           "Container to identify impairment-aware topology type.";
         reference
           "RFC8345: A YANG Data Model for Network Topologies.";
       }
     }

     augment "/nw:networks/nw:network" {
       when './nw:network-types/tet:te-topology'
          + '/oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Network augmentation for optical impairments data.";
       container otsis {
         presence "When present, it indicates that OTSi information is
                   reported.";
         config false;
         description
           "The information about the OTSis configured on the WDM-TE
            link.";
         list otsi-group {
           key "otsi-group-id";
           description
             "the list of possible OTSiG representing client digital
              stream.";
           leaf otsi-group-id {
             type string;
             description
               "A network-wide unique identifier of otsi-group element.
                It could be structured, e.g., as a URI or as a UUID.";
           }
           uses otsi-group;
         } // list of OTSiG
       }
       container templates {
         config false;
         description
           "Templates for set of parameters which can be common to
```

```
              multiple elements.";
         container roadm-path-impairments-sets {
           description
             "The top level container for the list of the set of
              optical impairments related to ROADM paths.";
           list roadm-path-impairments-set {
             key "roadm-path-impairments-set-id";
             description
               "The list of the set of optical impairments related to a
                ROADM path.";
             leaf roadm-path-impairments-set-id {
               type string;
               description
                 "The identifier of an element in the list of the set of
                  optical impairments related to a ROADM path.";
             }
             leaf description {
               type string;
               description
                 "The textual description of the set of optical
                  impairments related to a ROADM path.";
             }
             choice impairment-type {
               description
                 "Type path impairment.";
               case roadm-express-path {
                 list roadm-express-path {
                   key "frequency-range-id";
                   description
                     "The list of optical impairments on a ROADM express
                      path for different frequency ranges.

                      Two elements in the list MUST NOT have the same
                      range or overlapping ranges.";
                   uses l0-types:frequency-range-with-identifier;
                   uses roadm-common-path;
                 }
               }
               case roadm-add-path {
                 list roadm-add-path {
                   key "frequency-range-id";
                   description
                     "The list of optical impairments on a ROADM add
                      path for different frequency ranges.

                      Two elements in the list MUST NOT have the same
                      range or overlapping ranges.";
                   uses l0-types:frequency-range-with-identifier;
```

```
                uses roadm-add-path;
              }
            }
            case roadm-drop-path {
              list roadm-drop-path {
                key "frequency-range-id";
                description
                  "The list of optical impairments on a ROADM add
                   path for different frequency ranges.

                   Two elements in the list MUST NOT have the same
                   range or overlapping ranges.";
                uses l0-types:frequency-range-with-identifier;
                uses roadm-drop-path;
              }
            }
          }
        } // list roadm-path-impairments-set
      } // container roadm-path-impairments-sets
      container explicit-transceiver-modes {
        description
          "The top level container for the list of the
           transceivers' explicit modes.";
        list explicit-transceiver-mode {
          key "explicit-transceiver-mode-id";
          description
            "The list of the transceivers' explicit modes.";
          leaf explicit-transceiver-mode-id {
            type string;
            description
              "The identifier of the transceivers' explicit mode.";
          }
          uses l0-types:explicit-mode;
        } // list explicit-transceiver-mode
      } // container explicit-transceiver-modes
    } // container templates
  } // augment network

  augment "/nw:networks/nw:network/nw:node" {
    when '../nw:network-types/tet:te-topology'
       + '/oit:optical-impairment-topology' {
      description
        "This augment is only valid for Optical Impairment.";
    }
    description
      "Node augmentation for optical impairments data.";
    container transponders {
      presence
```

```
            "If present, it indicates that the list of transponders is
             reported.";
          config false;
          description
            "The top level container for the list of transponders.";
          list transponder {
            key "transponder-id";
            description
              "The list of transponders.";
            leaf transponder-id {
              type uint32;
              description
                "Transponder identifier.";
            }
            leaf termination-type-capabilities {
              type enumeration {
                enum tunnel-only {
                  description
                    "The transponder can only be used in an Optical
                     Tunnel termination configuration.";
                }
                enum 3r-only {
                  description
                    "The transponder can only be used in a 3R
                     configuration.";
                }
                enum 3r-or-tunnel {
                  description
                    "The transponder can be used either in an Optical
                     Tunnel termination configuration or in a 3R
                     configuration.";
                }
              }
              description
                "Describes whether the transponder can be used in an
                 Optical Tunnel termination configuration or in a 3R
                 configuration (or both).";
            }
            leaf supported-3r-mode {
              when '(../termination-type-capabilities = "3r-only") '
                 + 'or (../termination-type-capabilities = '
                 + '"3r-or-tunnel")' {
                description
                  "Applies only when the transponder supports 3R
                   configuration.";
              }
              type enumeration {
                enum unidir {
```

```
                description
                  "Unidirectional 3R configuration.";
              }
              enum bidir {
                description
                  "Bidirectional 3R configuration.";
              }
            }
            description
              "Describes the supported 3R configuration type.";
          }
          list transceiver {
            key "transceiver-id";
            min-elements 1;
            description
              "List of transceiver related to a transponder.";
            leaf transceiver-id {
              type uint32;
              description
                "Transceiver identifier.";
            }
            uses l0-types:transceiver-capabilities {
              augment "supported-modes/supported-mode/mode/"
                    + "explicit-mode/explicit-mode" {
                description
                  "Augment the explicit-mode container with the
                   proper leafref.";
                leaf explicit-transceiver-mode-ref {
                  type leafref {
                    path "../../../../../../../../oit:templates"
                       + "/oit:explicit-transceiver-modes"
                       + "/oit:explicit-transceiver-mode"
                       + "/oit:explicit-transceiver-mode-id";
                  }
                  description
                    "The reference to the explicit transceiver
                     mode template.";
                }
              }
            }
            leaf configured-mode {
              type union {
                type l0-types:unknown-value;
                type leafref {
                  path "../supported-modes/supported-mode/mode-id";
                }
              }
              description
```

```
                "Reference to the configured mode for transceiver
                 compatibility approach.

                 The 'unknown' value is used to report that no mode has
                 been configured and there is no default mode.

                 When not present, the configured-mode is not reported
                 by the server.";
            }
            uses l0-types:common-transceiver-param;
            container outgoing-otsi {
              when '../../../../../otsis' {
                description
                  "It applies only when the OTSi information is
                   reported.";
              }
              description
                "The OTSi generated by the transceiver's transmitter.";
              uses otsi-ref;
            }
            container incoming-otsi {
              when '../../../../../otsis' {
                description
                  "It applies only when the OTSi information is
                   reported.";
              }
              description
                "The OTSi received by the transceiver's receiver.";
              uses otsi-ref;
            }
            leaf configured-termination-type {
              type enumeration {
                enum unused-transceiver {
                  description
                    "The transcevier is not used.";
                }
                enum tunnel-termination {
                  description
                    "The transceiver is currently used in an Optical
                     Tunnel termination configuration.";
                }
                enum 3r-regeneration {
                  description
                    "The transceiver is currently used in a 3R
                     configuration.";
                }
              }
              description
```

```
                 "Describes whether the current configuration of the
                  transceiver is used in an Optical Tunnel termination
                  configuration or in a 3R configuration.

                  If empty, it means that the information about the
                  configured-termination-type is not reported.";
             }
           } // end of list of transceiver
         } // end list of transponder
       }
       container regen-groups {
         presence "When present, it indicates that the list of 3R groups
                   is reported.";
         config false;
         description
           "The top level container for the list of 3R groups.";
         list regen-group {
           key "group-id";
           description
             "The list of 3R groups.

              Any 3R group represent a group of transponder in which an
              electrical connectivity is either in place or could
              be dynamically provided, to associated transponders used
              for 3R regeneration.";
           leaf group-id {
             type uint32;
             description
               "Group identifier used an index to access elements in the
                list of 3R groups.";
           }
           leaf regen-metric {
             type uint32;
             description
               "The cost permits choice among different groups of
                transponders during path computation.";
           }
           leaf-list transponder-ref {
             type leafref {
               path "../../../transponders/transponder/transponder-id";
             }
             description
               "The list of transponders belonging to this 3R group.";
           }
         } // end 3R-group
       }
     }
```

```
     augment "/nw:networks/nw:network/nt:link/tet:te"
           + "/tet:te-link-attributes" {
       when '../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Optical Link augmentation for impairment data.";
       container oms-attributes {
         config false;
         description
           "OMS attributes.";
         uses oms-general-optical-params;
         uses media-channel-groups;
         uses oms-element;
       }
     }

     augment "/nw:networks/nw:network/nw:node/tet:te"
           + "/tet:tunnel-termination-point" {
       when '../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Tunnel termination point augmentation for impairment data.";
       list ttp-transceiver {
         when '../../../transponders' {
           description
             "It applies only when the list of transponders is
              reported.";
         }
         key "transponder-ref transceiver-ref";
         config false;
         min-elements 1;
         description
           "The list of the transceivers used by the TTP.";
         leaf transponder-ref {
           type leafref {
             path "../../../../transponders/transponder/transponder-id";
           }
           description
             "The reference to the transponder hosting the transceiver
              of the TTP.";
```

```
         }
         leaf transceiver-ref {
           type leafref {
             path "../../../../transponders/transponder"
                + "[transponder-id=current()/../transponder-ref]/"
                + "transceiver/transceiver-id";
           }
           description
             "The reference to the transceiver of the TTP.";
         }
       } // list of transceivers
     } // end of augment

     augment "/nw:networks/nw:network/nw:node/nt:termination-point" {
       when '../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment LTP";
       leaf protection-type {
         type identityref {
           base te-types:lsp-protection-type;
         }
         config false;
         description
           "The protection type that this LTP is capable of.

            When not present it indicates that the information about
            the protection type is not reported.";
       }
     }

     augment "/nw:networks/nw:network/nw:node/nt:termination-point"
           + "/tet:te" {
       when '../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment TE attributes of an LTP";
       leaf inter-layer-sequence-number {
         type uint32;
         config false;
```

```
          description
            "The inter-layer-sequence-number (ILSN) is used to report
             additional connectivity constraints between a client layer
             Link Termination Point (LTP), such as a muxponder port, and
             the server layer Tunnel Termination Point (TTP).

             A client service cannot be setup between two client layer
             LTPs which report different values of the ILSN.

             This attribute is not reported when there are no additional
             connectivity constraints.

             Therefore, a client service can be setup when at least one
             of the two client layer LTPs does not report any ILSN or
             both client layer LTPs report the same ILSN value and the
             corresponding server layer TTPs have at least one common
             server-layer switching capability and at least one common
             client-layer switching capability.";
        }
      }

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:information-source-entry/tet:connectivity-matrices" {
        when '../../../../nw:network-types/tet:te-topology/'
           + 'oit:optical-impairment-topology' {
          description
            "This augment is only valid for Optical Impairment
             topology.";
        }
        description
          "Augment default TE node connectivity matrix information
           source.";
        leaf roadm-path-impairments-set {
          type leafref {
            path "../../../../../oit:templates"
               + "/oit:roadm-path-impairments-sets"
               + "/oit:roadm-path-impairments-set"
               + "/oit:roadm-path-impairments-set-id";
          }
          config false;
          description
            "Pointer to optical impairments of the associated ROADM
             path.";
        }
      } // augmentation connectivity-matrices information-source

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:information-source-entry/tet:connectivity-matrices/"
```

```
            + "tet:connectivity-matrix" {
        when '../../../../../nw:network-types/tet:te-topology/'
           + 'oit:optical-impairment-topology' {
          description
            "This augment is only valid for Optical Impairment
             topology.";
        }
        description
          "Augment TE node connectivity matrix entry information
           source.";
        leaf roadm-path-impairments-set {
          type leafref {
            path "../../../../../../oit:templates"
               + "/oit:roadm-path-impairments-sets"
               + "/oit:roadm-path-impairments-set"
               + "/oit:roadm-path-impairments-set-id";
          }
          config false;
          description
            "Pointer to optical impairments of the associated ROADM
             path.";
        }
      } // augmentation connectivity-matrix information-source

      augment "/nw:networks/nw:network/nw:node/tet:te/"
            + "tet:te-node-attributes/tet:connectivity-matrices" {
        when '../../../../nw:network-types/tet:te-topology/'
           + 'oit:optical-impairment-topology' {
          description
            "This augment is only valid for Optical Impairment
             topology.";
        }
        description
          "Augment default TE node connectivity matrix.";
        leaf roadm-path-impairments-set {
          type leafref {
            path "../../../../../oit:templates"
               + "/oit:roadm-path-impairments-sets"
               + "/oit:roadm-path-impairments-set"
               + "/oit:roadm-path-impairments-set-id";
          }
          config false;
          description
            "Pointer to optical impairments of the associated ROADM
             path.";
        }
      } // augmentation connectivity-matrices
```

```
     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:te-node-attributes/"
           + "tet:connectivity-matrices/tet:connectivity-matrix" {
       when '../../../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment TE node connectivity matrix entry.";
       leaf roadm-path-impairments-set {
         type leafref {
           path "../../../../../../oit:templates"
              + "/oit:roadm-path-impairments-sets"
              + "/oit:roadm-path-impairments-set"
              + "/oit:roadm-path-impairments-set-id";
         }
         config false;
         description
           "Pointer to optical impairments of the associated ROADM
            path.";
       }
     } // augmentation connectivity-matrix

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:te-node-attributes/tet:connectivity-matrices/"
           + "tet:connectivity-matrix/tet:from" {
       when '../../../../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment the attributes for the 'from' LTP for the TE node
          connectivity matrix entry.";
       list additional-ltp {
         when "derived-from-or-self(../../../../../../"
            + "nt:termination-point"
            + "[nt:tp-id=current()/../../tet:to/tet:tp-ref]/"
            + "oit:protection-type,"
            + "'oit:otsi-protection')" {
           description
             "This list applies only when the 'to' LTP for this
              connectivity matrix entry supports individual OTSi(G)
              protection.";
         }
```

```
         key "ltp-ref";
         config false;
         description
           "The restricted list of the potential secondary LTPs that
            can be selected when the 'from' LTP of this connectivity
            matrix entry is selected as a working LTP.

            If this list is empty, all the other LTPs that can reach
            the 'to' LTP of this connectivity matrix entry can be
            selected as secondary LTPs.";
         leaf ltp-ref {
           type leafref {
             path "../../../../../../../nt:termination-point/nt:tp-id";
           }
           description
             "The reference to the potential secondary LTP that can be
              selected when the 'from' LTP of this connectivity matrix
              entry is selected as a working LTP.";
         }
         leaf roadm-path-impairments-set {
           type leafref {
             path "../../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the ROADM path between
              this secondary 'from' LTP and the 'to' LTP of this
              connectivity matrix entry.";
         }
       }
     } // augmentation connectivity-matrix from

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:te-node-attributes/tet:connectivity-matrices/"
           + "tet:connectivity-matrix/tet:to" {
       when '../../../../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment the attributes for the 'to' LTP for the TE node
          connectivity matrix entry.";
       list additional-ltp {
         when "derived-from-or-self(../../../../../../"
```

```
            + "nt:termination-point"
            + "[nt:tp-id=current()/../../tet:from/tet:tp-ref]/"
            + "oit:protection-type,"
            + "'oit:otsi-protection')" {
           description
             "This list applies only when the 'from' LTP for this
              connectivity matrix entry supports individual OTSi(G)
              protection.";
         }
         key "ltp-ref";
         config false;
         description
           "The restricted list of the potential secondary LTPs that
            can be selected when the 'to' LTP of this connectivity
            matrix entry is selected as a working LTP.

            If this list is empty, all the other LTPs that can be
            reached from the 'from' LTP of this connectivity matrix
            entry can be selected as secondary LTPs.";
         leaf ltp-ref {
           type leafref {
             path "../../../../../../../nt:termination-point/nt:tp-id";
           }
           description
             "The reference to the potential secondary LTP that can be
              selected when the 'to' LTP of this connectivity matrix
              entry is selected as a working LTP.";
         }
         leaf roadm-path-impairments-set {
           type leafref {
             path "../../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the ROADM path between
              the 'from' LTP of this connectivity matrix entry and this
              secondary LTP.";
         }
       }
     } // augmentation connectivity-matrix to

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:tunnel-termination-point/"
           + "tet:local-link-connectivities" {
       when '../../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
```

```
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment default TTP LLC.";
       leaf add-path-impairments-set {
         type leafref {
           path "../../../../../oit:templates"
              + "/oit:roadm-path-impairments-sets"
              + "/oit:roadm-path-impairments-set"
              + "/oit:roadm-path-impairments-set-id";
         }
         config false;
         description
           "Pointer to optical impairments of the associated ROADM
            path.";
       }
       leaf drop-path-impairments-set {
         type leafref {
           path "../../../../../oit:templates"
              + "/oit:roadm-path-impairments-sets"
              + "/oit:roadm-path-impairments-set"
              + "/oit:roadm-path-impairments-set-id";
         }
         config false;
         description
           "Pointer to optical impairments of the associated ROADM
            path.";
       }
     } // augmentation local-link-connectivities

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:tunnel-termination-point/"
           + "tet:local-link-connectivities/"
           + "tet:local-link-connectivity" {
       when '../../../../../nw:network-types/tet:te-topology/'
          + 'oit:optical-impairment-topology' {
         description
           "This augment is only valid for Optical Impairment
            topology.";
       }
       description
         "Augment TTP LLC entry.";
       leaf add-path-impairments-set {
         type leafref {
           path "../../../../../../oit:templates"
              + "/oit:roadm-path-impairments-sets"
```

```
              + "/oit:roadm-path-impairments-set"
              + "/oit:roadm-path-impairments-set-id";
         }
         config false;
         description
           "Pointer to optical impairments of the associated ROADM
            path.";
       }
       leaf drop-path-impairments-set {
         type leafref {
           path "../../../../../../oit:templates"
              + "/oit:roadm-path-impairments-sets"
              + "/oit:roadm-path-impairments-set"
              + "/oit:roadm-path-impairments-set-id";
         }
         config false;
         description
           "Pointer to optical impairments of the associated ROADM
            path.";
       }
       list llc-transceiver {
         key "ttp-transponder-ref ttp-transceiver-ref";
         config false;
         description
           "The list of transceivers having an LLC different from the
            default LLC.";
         leaf ttp-transponder-ref {
           type leafref {
             path "../../../../ttp-transceiver/transponder-ref";
           }
           description
             "The reference to the transponder hosting the transceiver
              of this LLCL entry.";
         }
         leaf ttp-transceiver-ref {
           type leafref {
             path "../../../../ttp-transceiver/transceiver-ref";
           }
           description
             "The reference to the transceiver of this LLCL entry.";
         }
         leaf is-allowed {
           type boolean;
           description
             "'true' - connectivity from this transceiver is allowed;
              'false' - connectivity from this transceiver is
              disallowed.";
         }
```

```
         leaf add-path-impairments-set {
           type leafref {
             path "../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the associated ROADM
              path.";
         }
         leaf drop-path-impairments-set {
           type leafref {
             path "../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the associated ROADM
              path.";
         }
       }
       list additional-ltp {
         when "derived-from-or-self(../../../tet:protection-type,"
            + "'oit:otsi-protection')" {
           description
             "This list applies only to TTPs that support individual
              OTSi(G) protection.";
         }
         key "ltp-ref";
         config false;
         description
           "The restricted list of the potential secondary LTPs that
            can be selected when the LTP associated with this LLCP
            entry is selected as a working LTP.

            If this list is empty, all the other LTPs that can be
            reached by this TTP can be selected as secondary LTPs.";
         leaf ltp-ref {
           type leafref {
             path "../../../../../../nt:termination-point/nt:tp-id";
           }
           description
             "The reference to potential secondary LTP that can be
              selected when the LTP associated with this LLCP entry is
              selected as a working LTP.";
         }
```

```
         leaf add-path-impairments-set {
           type leafref {
             path "../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the associated ROADM
              path.";
         }
         leaf drop-path-impairments-set {
           type leafref {
             path "../../../../../../../oit:templates"
                + "/oit:roadm-path-impairments-sets"
                + "/oit:roadm-path-impairments-set"
                + "/oit:roadm-path-impairments-set-id";
           }
           description
             "Pointer to optical impairments of the associated ROADM
              path.";
         }
       }
     } // augmentation local-link-connectivity

   }
   <CODE ENDS>
```

3.1. YANG Model Explanations

As indicated in [RFC8345], section 4.1, "When a network is of a certain type, it will contain a corresponding data node. Network types SHOULD always be represented using presence containers". The YANG model is in fact augmenting "nw:network-types/tet:te-topology" with the new presence container "optical-impairment-topology" representing an impairment-aware topology type.

As described in Section 2.3.1, the OTSi signals in the YANG model are described by augmenting the "nw:network" data node and each OTSi signal is uniquely identified by its otsi-carrier-id, which is unique within the scope the OTSiG the OTSi belongs to.

As described in Section 2.3.2, all OTSiGs are described in the YANG model by augmenting the "nw:network" data node and each OTSiG is uniquely identified by its otsi-group-id, which is unique within the network. Each OTSiG also contains a list of the OTSi signals belonging to the OTSiG.

Any OTSi signal is terminated by a transceiver and that is modeled as a function of the tunnel termination point (TTP) and a "ttp-transceiver" list of transceivers augmenting the "tunnel-termination-point".

The relationship between OTSi and the related transceiver is provided in the YANG model by the containers "incoming-otsi" for the OTSi received by the transceiver’s receiver and "outgoing-otsi" for the OTSi generated by the transceiver’s transmitter.

As described in Section 2.7, transponders are usually used to terminate a layer 0 tunnel. But, they also can be used to regenerate the signal and form a 3R regenarator. No new entity is needed in the model since 3R functionality is provided by an optical transponder pair. The YANG model provides two attributes related to 3R regenerators: "supported-termination-type" and "supported-3r-mode".

supported-termination-type is describing if an optical transponder is supporting tunnel termination only, or 3R regenerator only, or both.

supported-3r-mode gives the configuration of transponder pair providing the 3R functionality, if back-to-back (see Figure 6) or Cross-3R (see Figure 7).

The model also provides a "regen-group" list and each list entry represents a group of transponders that support the 3R functionality. "transponder-ref" is pointing to the transponders belonging to any specific group.

The data node "inter-layer-sequence-number" augments the termination point attribute to describe additional constraints between a client layer Link Termination Point (LTP), e.g., a muxponder port and a server layer LTP.

To improve scalability, the model is defining templates for both, "roadm-path-impairments-set", the list of the set of optical impairments related to ROADM paths (express, add and drop paths) and "explicit-transceiver-mode",the list of optical parameters related to a transceiver’s explicit mode providing the capability attributes and optical impairment limits of an explicit transceiver mode. These templates are also defined as "network" augmentation.

As stated in Section 2.6, the model defines three types of approaches to describes the transceiver capabilities (called "modes"):

* Standard Modes

* Organizational Modes

* Explicit Modes

These different modes (described in Section 2.6.1, Section 2.6.2, and Section 2.6.3) are defined under the "transponders" presence container augmenting the data node "node" as defined in [RFC8345]. If present, this container will indicate that the set of transponders/transceivers in a node is described with all the impairments attribute depending on the supported mode type of any specific transponder. The YANG model permits to describe the transponder capabilities in a mixed way (a transceiver can support more than one mode out of the three mode types).

Section 2.3 followed by Section 2.3.3, and Section 2.3.4 describe the OMS MCG and the OTS MCG and the model represents this entity as a WDM TE-link interconnecting two WDM-TE-nodes. The model augments the te-link-attributes defined in [RFC8795] with the optical impairments for the WDM TE-link of the layer-0 topology related to a specific network controller domain.

As described in detail in Section 2.10, the optical impairments imposed by passive or active optical ROADM components for the three different ROADM path types have to be taken into account when an OTSi signal crosses a ROADM node. The following two entities defined in [RFC8795] are used to describe the optical impairments for the 3 MC path types: "connectivity-matrix" for express paths and "local-link-connectivity-list" for Add/Drop paths crossing the ROADM.

A list of optical impairment sets "roadm-path-impairments-set" is defined under "templates", and this parameter set list entries will contain the optical impairments for express, add, and drop paths.

The connectivity-matrix is augmented with the optical impairment sets for the ROADM’s express-path contained in the "roadm-path-impairments-set", while the LLCL is augmented with the optical impairment sets contained in the "roadm-path-impairments-set" for the ROADM’s add-path and drop-path by using leafref "add-path-impairments-set" and leafref "drop-path-impairments-set".

In case OTSi protection is supported, a list of additional line LTPs is defined in the model to represent potential connectivity between an add-drop LTP/TTP and multiple line LTPs including the related optical impairments. See Section 2.11.1.2 for more details). Additional OTSi protection architectures are described in detail in Section 2.11.1.1 and Section 2.11.1.3.

4. Security Considerations

This section is based on the template in Section 3.7 of [I-D.ietf-netmod-rfc8407bis].

The "ietf-optical-impairment-topology" YANG module defines a data model that is designed to be accessed via YANG-based management protocols, such as NETCONF [RFC6241] and RESTCONF [RFC8040]. These YANG-based management protocols

(1) have to use a secure transport layer (e.g., SSH [RFC4252], TLS [RFC8446], and QUIC [RFC9000] and

(2) have to use mutual authentication.

The Network Configuration Access Control Model (NACM) [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are no particularly sensitive readable data nodes.

This YANG module uses groupings from other YANG modules that define nodes that may be considered sensitive or vulnerable in network environments. Refer to the Security Considerations of [I-D.ietf-ccamp-rfc9093-bis] for information as to which nodes may be considered sensitive or vulnerable in network environments.

Finally, the YANG module described in this document augments the "ietf-network" YANG module [RFC8345] and the "ietf-te-topology" YANG module [RFC8795] by adding data nodes. The security considerations for the subtrees described in those RFCs apply equally to the new data nodes that this module adds.

5. IANA Considerations

This document registers the following namespace URIs in the IETF XML registry [RFC3688]:

```
--------------------------------------------------------------------
URI: urn:ietf:params:xml:ns:yang:ietf-optical-impairment-topology
Registrant Contact: The IESG.
XML: N/A, the requested URI is an XML namespace.
--------------------------------------------------------------------
```

This document registers the following YANG module in the YANG Module Names registry [RFC7950]:

```
--------------------------------------------------------------------
name:      ietf-optical-impairment-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-optical-impairment-
topology
prefix:    oit
maintained by IANA? N
reference: RFC XXXX (TDB)
--------------------------------------------------------------------
```

6. Acknowledgments

We thank Daniele Ceccarelli and Oscar G. De Dios for useful discussions and motivation for this work.

7. References

7.1. Normative References

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Appendix A. YANG Model Tree Structure

```
module: ietf-optical-impairment-topology

  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw optical-impairment-topology!
  augment /nw:networks/nw:network:
    +--ro otsis!
    |  +--ro otsi-group* [otsi-group-id]
```

```
       |     +--ro otsi-group-id    string
       |     +--ro otsi* [carrier-id]
       |        +--ro carrier-id           uint16
       |        +--ro carrier-frequency?   union
       |        +--ro e2e-mc-path-id*      uint16
       +--ro templates
          +--ro roadm-path-impairments-sets
          |  +--ro roadm-path-impairments-set*
          |          [roadm-path-impairments-set-id]
          |     +--ro roadm-path-impairments-set-id    string
          |     +--ro description?                     string
          |     +--ro (impairment-type)?
          |        +--:(roadm-express-path)
          |        |  +--ro roadm-express-path* [frequency-range-id]
          |        |     +--ro frequency-range-id        uint16
          |        |     +--ro frequency-range
          |        |     |  +--ro lower-frequency    frequency-thz
          |        |     |  +--ro upper-frequency    frequency-thz
          |        |     +--ro roadm-pmd?                union
          |        |     +--ro roadm-cd?
          |        |     |       l0-types:decimal-5-or-unknown
          |        |     +--ro roadm-pdl?
          |        |     |       l0-types:power-loss-or-unknown
          |        |     +--ro roadm-inband-crosstalk?
          |        |     |       l0-types:decimal-2-or-unknown
          |        |     +--ro roadm-maxloss?
          |        |             l0-types:power-loss-or-unknown
          |        +--:(roadm-add-path)
          |        |  +--ro roadm-add-path* [frequency-range-id]
          |        |     +--ro frequency-range-id        uint16
          |        |     +--ro frequency-range
          |        |     |  +--ro lower-frequency    frequency-thz
          |        |     |  +--ro upper-frequency    frequency-thz
          |        |     +--ro roadm-pmd?                union
          |        |     +--ro roadm-cd?
          |        |     |       l0-types:decimal-5-or-unknown
          |        |     +--ro roadm-pdl?
          |        |     |       l0-types:power-loss-or-unknown
          |        |     +--ro roadm-inband-crosstalk?
          |        |     |       l0-types:decimal-2-or-unknown
          |        |     +--ro roadm-maxloss?
          |        |     |       l0-types:power-loss-or-unknown
          |        |     +--ro roadm-pmax?
          |        |     |       l0-types:power-dbm-or-unknown
          |        |     +--ro roadm-osnr?
          |        |     |       l0-types:snr-or-unknown
          |        |     +--ro roadm-noise-figure?
          |        |             l0-types:decimal-5-or-unknown
```

```
          |        +--:(roadm-drop-path)
          |           +--ro roadm-drop-path* [frequency-range-id]
          |              +--ro frequency-range-id        uint16
          |              +--ro frequency-range
          |              |  +--ro lower-frequency    frequency-thz
          |              |  +--ro upper-frequency    frequency-thz
          |              +--ro roadm-pmd?                union
          |              +--ro roadm-cd?
          |              |       l0-types:decimal-5-or-unknown
          |              +--ro roadm-pdl?
          |              |       l0-types:power-loss-or-unknown
          |              +--ro roadm-inband-crosstalk?
          |              |       l0-types:decimal-2-or-unknown
          |              +--ro roadm-maxloss?
          |              |       l0-types:power-loss-or-unknown
          |              +--ro roadm-minloss?
          |              |       l0-types:power-loss-or-unknown
          |              +--ro roadm-typloss?
          |              |       l0-types:power-loss-or-unknown
          |              +--ro roadm-pmin?
          |              |       l0-types:power-dbm-or-unknown
          |              +--ro roadm-pmax?
          |              |       l0-types:power-dbm-or-unknown
          |              +--ro roadm-ptyp?
          |              |       l0-types:power-dbm-or-unknown
          |              +--ro roadm-osnr?
          |              |       l0-types:snr-or-unknown
          |              +--ro roadm-noise-figure?
          |                      l0-types:decimal-5-or-unknown
          +--ro explicit-transceiver-modes
             +--ro explicit-transceiver-mode*
                     [explicit-transceiver-mode-id]
                +--ro explicit-transceiver-mode-id        string
                +--ro line-coding-bitrate?                identityref
                +--ro bitrate?                            uint16
                +--ro max-diff-group-delay?               decimal-2
                +--ro max-chromatic-dispersion?           decimal-2
                +--ro cd-penalty* [cd-value]
                |  +--ro cd-value         decimal-2
                |  +--ro penalty-value    union
                +--ro max-polarization-mode-dispersion?   decimal-2
                +--ro pmd-penalty* [pmd-value]
                |  +--ro pmd-value        decimal-2
                |  +--ro penalty-value    union
                +--ro max-polarization-dependent-loss
                |       power-loss-or-unknown
                +--ro pdl-penalty* [pdl-value]
                |  +--ro pdl-value        power-loss
```

```
                |  +--ro penalty-value    union
                +--ro available-modulation-type?          identityref
                +--ro min-OSNR?                           snr
                +--ro rx-ref-channel-power?               power-dbm
                +--ro rx-channel-power-penalty* [rx-channel-power-value]
                |  +--ro rx-channel-power-value    power-dbm
                |  +--ro penalty-value             union
                +--ro min-Q-factor?                       decimal-2
                +--ro available-baud-rate?                decimal64
                +--ro roll-off?                           decimal64
                +--ro min-carrier-spacing?                frequency-ghz
                +--ro available-fec-type?                 identityref
                +--ro fec-code-rate?                      decimal64
                +--ro fec-threshold?                      decimal64
                +--ro in-band-osnr?                       snr
                +--ro out-of-band-osnr?                   snr
                +--ro tx-polarization-power-difference?   power-ratio
                +--ro polarization-skew?                  decimal-2
     augment /nw:networks/nw:network/nw:node:
       +--ro transponders!
       |  +--ro transponder* [transponder-id]
       |     +--ro transponder-id                   uint32
       |     +--ro termination-type-capabilities?   enumeration
       |     +--ro supported-3r-mode?               enumeration
       |     +--ro transceiver* [transceiver-id]
       |        +--ro transceiver-id                 uint32
       |        +--ro supported-modes!
       |        |  +--ro supported-mode* [mode-id]
       |        |     +--ro mode-id                       string
       |        |     +--ro (mode)
       |        |        +--:(g.698.2)
       |        |        |  +--ro g.698.2
       |        |        |     +--ro standard-mode
       |        |        |     |       standard-mode
       |        |        |     +--ro line-coding-bitrate*
       |        |        |     |       identityref
       |        |        |     +--ro transceiver-tuning-range
       |        |        |     |  +--ro min-central-frequency?
       |        |        |     |  |       frequency-thz
       |        |        |     |  +--ro max-central-frequency?
       |        |        |     |  |       frequency-thz
       |        |        |     |  +--ro transceiver-tunability-granular\
   ity?
       |        |        |     |          frequency-ghz
       |        |        |     +--ro tx-channel-power-min?
       |        |        |     |       power-dbm
       |        |        |     +--ro tx-channel-power-max?
       |        |        |     |       power-dbm
```

```
        |        |        |     +--ro rx-channel-power-min?
        |        |        |     |       power-dbm
        |        |        |     +--ro rx-channel-power-max?
        |        |        |     |       power-dbm
        |        |        |     +--ro rx-total-power-max?
        |        |        |             power-dbm
        |        |        +--:(organizational-mode)
        |        |        |  +--ro organizational-mode
        |        |        |     +--ro operational-mode
        |        |        |     |       operational-mode
        |        |        |     +--ro organization-identifier
        |        |        |     |       organization-identifier
        |        |        |     +--ro line-coding-bitrate*
        |        |        |     |       identityref
        |        |        |     +--ro transceiver-tuning-range
        |        |        |     |  +--ro min-central-frequency?
        |        |        |     |  |       frequency-thz
        |        |        |     |  +--ro max-central-frequency?
        |        |        |     |  |       frequency-thz
        |        |        |     |  +--ro transceiver-tunability-granular\
ity?
        |        |        |     |          frequency-ghz
        |        |        |     +--ro tx-channel-power-min?
        |        |        |     |       power-dbm
        |        |        |     +--ro tx-channel-power-max?
        |        |        |     |       power-dbm
        |        |        |     +--ro rx-channel-power-min?
        |        |        |     |       power-dbm
        |        |        |     +--ro rx-channel-power-max?
        |        |        |     |       power-dbm
        |        |        |     +--ro rx-total-power-max?
        |        |        |             power-dbm
        |        |        +--:(explicit-mode)
        |        |           +--ro explicit-mode
        |        |              +--ro transceiver-tuning-range
        |        |              |  +--ro min-central-frequency?
        |        |              |  |       frequency-thz
        |        |              |  +--ro max-central-frequency?
        |        |              |  |       frequency-thz
        |        |              |  +--ro transceiver-tunability-granular\
ity?
        |        |              |          frequency-ghz
        |        |              +--ro tx-channel-power-min?
        |        |              |       power-dbm
        |        |              +--ro tx-channel-power-max?
        |        |              |       power-dbm
        |        |              +--ro rx-channel-power-min?
        |        |              |       power-dbm
```

```
     |        |              +--ro rx-channel-power-max?
     |        |              |       power-dbm
     |        |              +--ro rx-total-power-max?
     |        |              |       power-dbm
     |        |              +--ro compatible-modes
     |        |              |  +--ro supported-application-code*
     |        |              |  |       leafref
     |        |              |  +--ro supported-organizational-mode*
     |        |              |          leafref
     |        |              +--ro explicit-transceiver-mode-ref?
     |        |                      leafref
     |        +--ro configured-mode?              union
     |        +--ro line-coding-bitrate?          identityref
     |        +--ro tx-channel-power?
     |        |       power-dbm-or-unknown
     |        +--ro rx-channel-power?
     |        |       power-dbm-or-unknown
     |        +--ro rx-total-power?
     |        |       power-dbm-or-unknown
     |        +--ro outgoing-otsi
     |        |  +--ro otsi-group-ref?   leafref
     |        |  +--ro otsi-ref?         leafref
     |        +--ro incoming-otsi
     |        |  +--ro otsi-group-ref?   leafref
     |        |  +--ro otsi-ref?         leafref
     |        +--ro configured-termination-type?   enumeration
     +--ro regen-groups!
        +--ro regen-group* [group-id]
           +--ro group-id           uint32
           +--ro regen-metric?      uint32
           +--ro transponder-ref*
                   -> ../../../transponders/transponder/transponder-id
   augment /nw:networks/nw:network/nt:link/tet:te
             /tet:te-link-attributes:
     +--ro oms-attributes
        +--ro generalized-snr?        l0-types:snr
        +--ro equalization-mode?      identityref
        +--ro power-param
        |  +--ro nominal-carrier-power?
        |  |       l0-types:power-dbm-or-unknown
        |  +--ro nominal-psd?             l0-types:psd-or-unknown
        +--ro media-channel-groups!
        |  +--ro media-channel-group* [otsi-group-ref]
        |     +--ro otsi-group-ref    leafref
        |     +--ro media-channel* [media-channel-id]
        |        +--ro media-channel-id    int16
        |        +--ro flexi-n?            flexi-n
        |        +--ro flexi-m?            flexi-m
```

```
          |        +--ro otsi-ref* [carrier-ref]
          |        |  +--ro carrier-ref        leafref
          |        |  +--ro e2e-mc-path-ref*   leafref
          |        +--ro delta-power?
          |                l0-types:power-ratio-or-unknown
          +--ro oms-elements!
             +--ro oms-element* [elt-index]
                +--ro elt-index                  uint16
                +--ro oms-element-uid?           union
                +--ro reverse-element-ref
                |  +--ro link-ref?
                |  |       -> ../../../../../../../../nt:link/link-id
                |  +--ro oms-element-ref*   leafref
                +--ro (element)
                   +--:(amplifier)
                   |  +--ro geolocation
                   |  |  +--ro altitude?    int64
                   |  |  +--ro latitude?    geographic-coordinate-degree
                   |  |  +--ro longitude?   geographic-coordinate-degree
                   |  +--ro amplifier
                   |     +--ro type-variety    string
                   |     +--ro operational
                   |        +--ro amplifier-element*
                   |                [frequency-range-id stage-order]
                   |           +--ro frequency-range-id
                   |           |       uint16
                   |           +--ro frequency-range
                   |           |  +--ro lower-frequency    frequency-thz
                   |           |  +--ro upper-frequency    frequency-thz
                   |           +--ro stage-order
                   |           |       uint8
                   |           +--ro name?
                   |           |       string
                   |           +--ro type-variety?
                   |           |       string
                   |           +--ro power-param
                   |           |  +--ro (power-param)
                   |           |     +--:(channel-power)
                   |           |     |  +--ro nominal-carrier-power
                   |           |     |          l0-types:power-dbm-or-u\
   nknown
                   |           |     +--:(power-spectral-density)
                   |           |        +--ro nominal-psd
                   |           |                l0-types:psd-or-unknown
                   |           +--ro pdl?
                   |           |       l0-types:power-loss-or-unknown
                   |           +--ro (amplifier-element-type)
                   |              +--:(optical-amplifier)
```

```
                |              |  +--ro optical-amplifier
                |              |     +--ro actual-gain
                |              |     |       l0-types:power-gain-or-\
   unknown
                |              |     +--ro in-voa?
                |              |     |       l0-types:power-loss-or-\
   unknown
                |              |     +--ro out-voa?
                |              |     |       l0-types:power-loss-or-\
   unknown
                |              |     +--ro tilt-target
                |              |     |       l0-types:decimal-2-or-u\
   nknown
                |              |     +--ro total-output-power
                |              |     |       l0-types:power-dbm-or-u\
   nknown
                |              |     +--ro raman-direction?
                |              |     |       enumeration
                |              |     +--ro raman-pump* [pump-id]
                |              |        +--ro pump-id      uint16
                |              |        +--ro frequency?
                |              |        |       l0-types:frequency-t\
   hz
                |              |        +--ro power?
                |              |                l0-types:decimal-2-o\
   r-unknown
                |              +--:(dynamic-gain-equalizer)
                |                 +--ro dynamic-gain-equalizer!
                |                    +--ro media-channel* [flexi-n]
                |                       +--ro flexi-n        flexi-n
                |                       +--ro flexi-m        flexi-m
                |                       +--ro delta-power?
                |                               l0-types:power-ratio\
   -or-unknown
                +--:(fiber)
                |  +--ro fiber
                |     +--ro type-variety    string
                |     +--ro length
                |     |       l0-types:decimal-2-or-unknown
                |     +--ro loss-coef
                |     |       l0-types:decimal-2-or-unknown
                |     +--ro total-loss?
                |     |       l0-types:power-loss-or-unknown
                |     +--ro pmd?
                |     |       l0-types:decimal-2-or-unknown
                |     +--ro conn-in?
                |     |       l0-types:power-loss-or-unknown
                |     +--ro conn-out?
```

```
                 |             l0-types:power-loss-or-unknown
                 +--:(concentrated-loss)
                    +--ro concentrated-loss
                       +--ro loss    l0-types:power-loss-or-unknown
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:tunnel-termination-point:
       +--ro ttp-transceiver* [transponder-ref transceiver-ref]
          +--ro transponder-ref
          |       -> ../../../../transponders/transponder/transponder-id
          +--ro transceiver-ref    leafref
     augment /nw:networks/nw:network/nw:node/nt:termination-point:
       +--ro protection-type?   identityref
     augment /nw:networks/nw:network/nw:node/nt:termination-point
               /tet:te:
       +--ro inter-layer-sequence-number?   uint32
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:information-source-entry/tet:connectivity-matrices:
       +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:information-source-entry/tet:connectivity-matrices
               /tet:connectivity-matrix:
       +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:te-node-attributes/tet:connectivity-matrices:
       +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:te-node-attributes/tet:connectivity-matrices
               /tet:connectivity-matrix:
       +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:te-node-attributes/tet:connectivity-matrices
               /tet:connectivity-matrix/tet:from:
       +--ro additional-ltp* [ltp-ref]
          +--ro ltp-ref
          |       -> ../../../../../../../nt:termination-point/tp-id
          +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:te-node-attributes/tet:connectivity-matrices
               /tet:connectivity-matrix/tet:to:
       +--ro additional-ltp* [ltp-ref]
          +--ro ltp-ref
          |       -> ../../../../../../../nt:termination-point/tp-id
          +--ro roadm-path-impairments-set?   leafref
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:tunnel-termination-point
               /tet:local-link-connectivities:
       +--ro add-path-impairments-set?    leafref
       +--ro drop-path-impairments-set?   leafref
```

```
     augment /nw:networks/nw:network/nw:node/tet:te
               /tet:tunnel-termination-point
               /tet:local-link-connectivities
               /tet:local-link-connectivity:
       +--ro add-path-impairments-set?    leafref
       +--ro drop-path-impairments-set?   leafref
       +--ro llc-transceiver* [ttp-transponder-ref ttp-transceiver-ref]
       |  +--ro ttp-transponder-ref
       |  |       -> ../../../../ttp-transceiver/transponder-ref
       |  +--ro ttp-transceiver-ref
       |  |       -> ../../../../ttp-transceiver/transceiver-ref
       |  +--ro is-allowed?                  boolean
       |  +--ro add-path-impairments-set?    leafref
       |  +--ro drop-path-impairments-set?   leafref
       +--ro additional-ltp* [ltp-ref]
          +--ro ltp-ref
          |       -> ../../../../../../nt:termination-point/tp-id
          +--ro add-path-impairments-set?    leafref
          +--ro drop-path-impairments-set?   leafref
```

Appendix B. JSON Code Examples for Optical Protection Uses Cases

(1) JSON example for use case in Section 2.11.1.1 with full and with restricted connectivity:

The JSON example below addresses the optical protection use case for TTPs associated with local optical transponders (integrated WDM-TE-node):

* where full connectivity exists between the ROADM add-drop ports and the ROADM ports for the different ROADM degrees illustrated in Figure 27 below.
* where restricted connectivity exists between the ROADM add-drop ports and the ROADM ports for the different ROADM degrees illustrated in Figure 28 below.

Note that Figure 27 and Figure 28 illustrate the connectivity for a single TTP only, i.e., the figures are not showing TTP-1, TTP-2, TTP-3, and TTP-4, which are used in the JSON code example below.

The connectivity is reflected in the local-link-connectivities between the TTP associated with the transceiver of the local OT and the LTPs that can be reached including the optical impairments for the different paths.

```
      +--------------------------------------------------------------+
      |                                       ROADM                  |
      |                          +--------------------------------+  |
      |  Local OT     Splitter   |                        ___     |  |
      |  +-------+   +-------+  AD1      ___             |   \  Line |
      |  |    TTP|   |    ---o-->o-     /   |       /----o    | LTP 1|
      |  |  +----|   |   /   |   | \   |    o------/     | 1  o------o->
    --o->|  | Tx o-->o--o  5 |   |  \  |    |           -o    |   |  |
      |  |  +----|   |   \   |  AD2  --o  4 o-\        / |___/    |  |
    <-o--|  | Rx o   |    ---o-->o-    |    |  \      /       DEG1|  |
      |  |  +----|   +-------+   | \   |    o-  \    /    ___     |  |
      |  |       |               |  |   \___| \  \  /    |   \  Line |
      |  +-------+      internal |  |          \  \------o    | LTP 2|
      |                 AD ports |  |           \ /      | 2  o------o->
      |                          |  |    ___     \   /---o    |    |  |
      |                          o  |   /   |   / \ /    |___/    |  |
      |                          |  |  |    o--/   \          DEG2|  |
      |                          |   \ |    |     / \     ___     |  |
      |                          |    -o  6 o----/   \   |   \  Line |
      |                          |     |    |         \--o    | LTP 3|
      |                          |     |    o----\       | 3  o------o->
      |                          o      \___|     \------o    |    |  |
      |                          |                       |___/    |  |
      |                          |                            DEG3|  |
      |                          +--------------------------------+  |
      +--------------------------------------------------------------+
```

Figure 27: Protected TTP with Full Connectivity between ROADM Add-Drop Ports and ROADM Degree Ports

```
      +--------------------------------------------------------------+
      |                                       ROADM                  |
      |                          +--------------------------------+  |
      |  Local OT     Splitter   |                        ___     |  |
      |  +-------+   +-------+  AD1       ___            |   \  Line |
      |  |    TTP|   |    ---o-->o--     /   |       /---o    | LTP 1|
      |  |  +----|   |   /   |   |  \   |    o------/    | 1  o------o->
    --o->|  | Tx o-->o--o  5 |   |   ---o  4 |         /-o    |   |  |
      |  |  +----|   |   \   |  AD2     |    o-\      /  |___/    |  |
    <-o--|  | Rx o   |    ---o-->o--     \___|  \    /        DEG1|  |
      |  |  +----|   +-------+   |  \     ___    \   |    ___     |  |
      |  |       |               |   \   /   |    \  |   |   \  Line |
      |  +-------+      internal |    \ |    o-------/   o    | LTP 2|
      |                 AD ports |     -o  6 |      \    | 2  o------o->
      |                          |      |    o-------\---o    |   |  |
      |                          o       \___|        |  |___/    |  |
      |                          |                    |       DEG2|  |
      |                          |                    |   ___     |  |
      |                          |                    |  |   \  Line |
      |                          |                    \--o    | LTP 3|
      |                          |                       | 3  o------o->
      |                          o                       o    |   |  |
      |                          |                       |___/    |  |
      |                          |                            DEG3|  |
      |                          +--------------------------------+  |
      +--------------------------------------------------------------+
```

Figure 28: Protected TTP with Restricted Connectivity between ROADM Add-Drop Ports and ROADM Degree Ports


```
=============== NOTE: '\\' line wrapping per RFC 8792 ===============

{
  "ietf-network:networks": {
    "network": [
      {
        "network-id": "example:WDM-Network-2",
        "network-types": {
          "ietf-te-topology:te-topology": {
            "ietf-optical-impairment-topology:optical-impairment-top\
\ology": {}
          }
        },
        "ietf-te-topology:te-topology-identifier": {
          "topology-id": "WDM-Network-1"
        },
        "ietf-te-topology:te": {},
```

```
          "ietf-optical-impairment-topology:templates": {
            "roadm-path-impairments-sets": {
                "roadm-path-impairments-set": [
                    {
                      "roadm-path-impairments-set-id": "1",
                      "description": "Add path impairments from TTP 1 \
   \or TTP 2 to any LTP",

                      "roadm-add-path": [
                        {
                          "frequency-range-id": 0,
                          "frequency-range": {
                              "lower-frequency": "191.3",
                              "upper-frequency": "196.1"
                          }
                        }
                      ]
                    },
                    {
                      "roadm-path-impairments-set-id": "2",
                       "description": "Add path impairments from TTP 3\
   \ or TTP 4 to LTP1 or LTP3, thorugh AD1",

                      "roadm-add-path": [
                        {
                          "frequency-range-id": 0,
                            "frequency-range": {
                              "lower-frequency": "191.3",
                              "upper-frequency": "196.1"
                            }
                        }
                      ]
                    },
                    {
                      "roadm-path-impairments-set-id": "3",
                      "description": "Add path impairments from TTP 3 \
   \or TTP 4 to LTP1 or LTP2, thorugh AD2",

                      "roadm-add-path": [
                        {
                          "frequency-range-id": 0,
                          "frequency-range": {
                              "lower-frequency": "191.3",
                              "upper-frequency": "196.1"
                          }
                        }
                      ]
                    }
```

```
                 ]
               }
             },
             "node": [
               {
                 "node-id": "example:WDM-TE-Node-1",
                 "ietf-te-topology:te-node-id": "192.0.2.1",
                 "ietf-te-topology:te": {
                   "tunnel-termination-point": [
                     {
                       "tunnel-tp-id": "MQ==",
                       "protection-type": "ietf-optical-impairment-topolo\
   \gy:otsi-protection",
                       "local-link-connectivities": {
                         "is-allowed": true,
                         "ietf-optical-impairment-topology:add-path-impai\
   \rments-set": "1"
                       }
                     },
                     {
                       "tunnel-tp-id": "Mg==",
                       "protection-type": "ietf-optical-impairment-topolo\
   \gy:otsi-protection",
                       "local-link-connectivities": {
                         "is-allowed": true,
                         "ietf-optical-impairment-topology:add-path-impai\
   \rments-set": "1",
                         "local-link-connectivity": [
                           {
                             "link-tp-ref": "example:LTP-1",
                             "ietf-optical-impairment-topology:additional\
   \-ltp": [
                               {
                                 "ltp-ref": "example:LTP-2"
                               },
                               {
                                 "ltp-ref": "example:LTP-3"
                               }
                             ]
                           },
                           {
                             "link-tp-ref": "example:LTP-2",
                             "ietf-optical-impairment-topology:additional\
   \-ltp": [
                               {
                                 "ltp-ref": "example:LTP-1"
                               },
                               {
```

```
                              "ltp-ref": "example:LTP-3"
                            }
                          ]
                        },
                        {
                        "link-tp-ref": "example:LTP-3",
                          "ietf-optical-impairment-topology:additional\
   \-ltp": [
                            {
                              "ltp-ref": "example:LTP-1"
                            },
                            {
                              "ltp-ref": "example:LTP-2"
                            }
                          ]
                        }
                      ]
                    }
                  },
                  {
                    "tunnel-tp-id": "Mw==",
                    "protection-type": "ietf-optical-impairment-topolo\
   \gy:otsi-protection",
                    "local-link-connectivities": {
                      "is-allowed": false,
                      "local-link-connectivity": [
                        {
                          "link-tp-ref": "example:LTP-1",
                          "is-allowed": true,
                          "ietf-optical-impairment-topology:add-path-i\
   \mpairments-set": "2",
                          "ietf-optical-impairment-topology:additional\
   \-ltp": [
                            {
                              "ltp-ref": "example:LTP-3",
                              "add-path-impairments-set": "2"
                            },
                            {
                              "ltp-ref": "example:LTP-2",
                              "add-path-impairments-set": "3"
                            }
                          ]
                        },
                        {
                          "link-tp-ref": "example:LTP-3",
                          "is-allowed": true,
                          "ietf-optical-impairment-topology:add-path-i\
   \mpairments-set": "2",
```

```
                           "ietf-optical-impairment-topology:additional\
   \-ltp": [
                             {
                               "ltp-ref": "example:LTP-1",
                               "add-path-impairments-set": "3"
                             },
                             {
                               "ltp-ref": "example:LTP-2",
                               "add-path-impairments-set": "3"
                             }
                           ]
                         }
                       ]
                     }
                   },
                   {
                     "tunnel-tp-id": "NA==",
                     "protection-type": "ietf-optical-impairment-topolo\
   \gy:otsi-protection",
                     "local-link-connectivities": {
                       "is-allowed": false,
                       "local-link-connectivity": [
                         {
                           "link-tp-ref": "example:LTP-1",
                           "is-allowed": true,
                           "ietf-optical-impairment-topology:add-path-i\
   \mpairments-set": "3",
                           "ietf-optical-impairment-topology:additional\
   \-ltp": [
                             {
                               "ltp-ref": "example:LTP-3",
                               "add-path-impairments-set": "2"
                             },
                             {
                               "ltp-ref": "example:LTP-2",
                               "add-path-impairments-set": "3"
                             }
                           ]
                         },
                         {
                           "link-tp-ref": "example:LTP-2",
                           "is-allowed": true,
                           "ietf-optical-impairment-topology:add-path-i\
   \mpairments-set": "3",
                           "ietf-optical-impairment-topology:additional\
   \-ltp": [
                             {
                               "ltp-ref": "example:LTP-1",
```

```
                              "add-path-impairments-set": "3"
                            },
                            {
                              "ltp-ref": "example:LTP-3",
                              "add-path-impairments-set": "2"
                            }
                          ]
                        },
                        {
                          "link-tp-ref": "example:LTP-3",
                          "is-allowed": true,
                          "ietf-optical-impairment-topology:add-path-i\
   \mpairments-set": "2",
                          "ietf-optical-impairment-topology:additional\
   \-ltp": [
                            {
                              "ltp-ref": "example:LTP-1",
                              "add-path-impairments-set": "3"
                            },
                            {
                              "ltp-ref": "example:LTP-2",
                              "add-path-impairments-set": "3"
                            }
                          ]
                        }
                      ]
                    }
                  }
                ]
              },
              "ietf-network-topology:termination-point": [
                {
                  "tp-id": "example:LTP-1"
                },
                {
                  "tp-id": "example:LTP-2"
                },
                {
                  "tp-id": "example:LTP-3"
                }
              ]
            }
          ]
        }
      ]
    }
  }
```

(2) JSON example for use case in Section 2.11.1.2 with restricted connectivity:

The JSON example below addresses the optical protection use case where the optical transponder is not part of the WDM-TE-node containing the ROADM function (WDM-TE-node-2) but is part of a separate WDM-TE-node (WDM-TE-node-1) containing one or more optical transponders (remote OTs). As described in Section 2.11.1.2, a TE-link interconnects the remote OT with an add-drop port of WDM-TE-node-2. This is illustrated in Figure 29.

In this use case, the connectivity is reflected in the connectivity-matrix describing the connectivity between the LTPs representing an add-drop port in WDM-TE-node-2 connected to the transceiver of a remote OT and the LTPs associated with the different ROADM degrees including the optical impairments for the different paths.

```
     WDM-TE-node 1                   WDM-TE-node 2

                  +--------------------------------------------------+
                  |  LTP 20                               ___        |
      +-------+   |  +-------+     AD 1  ___             |   \  Line |
      |   TTP1|   |  |    ---o-----     /   |       /----o    | LTP 1|
      |  +----|   |  |   /   |     \   |    o------/     | 1  o------o->
    --o->| Tx o---o->o--o  5 |      \--o    |           -o    |      |
      |  +----|   |  |   \   |         |  4 |          / |___/       |
    <-o--| Rx o   |  |    ---o-\    /--o    |         /         DEG 1|
      |  +----|   |  +-------+  \   |  |    o-       /    ___        |
      |       |   |   Splitter   \  |   \___| \     /    |   \  Line |
      |       |   |  +-------+   |  |          \         o    | LTP 2|
      |   TTP2|   |  |    ---o---|--/           \ /      | 2  o------o->
      |  +----|   |  |   /   |   |       ___     \   /---o    |      |
    --o->| Tx o---o->o--o  5 |    \     /   |   / \ /    |___/       |
      |  +----|   |  |   \   |     \   |    o--/   \           DEG 2 |
    <-o--| Rx o   |  |    ---o--\   \--o    |     / \     ___        |
      |  +----|   |  +-------+   \     |    |    /   \   |   \  Line |
      |       |   |  LTP 30       \----o  6 |   /     \--o    | LTP 3|
      |   TTP3|   |                    |    o--/         | 3  o------o->
      |  +----|   |          /-------->o    |            o    |      |
    --o->| Tx o---o---------/          |    |            |___/       |
      |  +----|   |  LTP 40             \___|                  DEG 3 |
    <-o--| Rx o   |                AD 2                              |
      |  +----|   |                                                  |
      |       |   |                                                  |
      +-------+   |                                                  |
                  |                                                  |
                  +--------------------------------------------------+
```

Figure 29: JSON Example for Restricted Connectivity between ROADM Add-Drop Ports and ROADM Degree Ports


```
=============== NOTE: '\\' line wrapping per RFC 8792 ===============

{
  "ietf-network:networks": {
    "network": [
      {
        "network-id": "example:WDM-Network-2",
        "network-types": {
          "ietf-te-topology:te-topology": {
            "ietf-optical-impairment-topology:optical-impairment-top\
\ology": {}
          }
        },
        "ietf-te-topology:te-topology-identifier": {
          "topology-id": "WDM-Network-1"
        },
        "ietf-te-topology:te": {},
        "ietf-optical-impairment-topology:templates": {
          "roadm-path-impairments-sets": {
              "roadm-path-impairments-set": [
                  {
                    "roadm-path-impairments-set-id": "1",

                    "roadm-add-path": [
                      {
                        "frequency-range-id": 0,
                        "frequency-range": {
                            "lower-frequency": "191.3",
                            "upper-frequency": "196.1"
                        }
                      }
                    ]
                  },
                  {
                    "roadm-path-impairments-set-id": "2",
                    "description": "Add path impairments from LTP 20\
\ or LTP 30 to LTP 1 or LTP3, through AD1",

                    "roadm-add-path": [
                      {
                        "frequency-range-id": 0,
                          "frequency-range": {
                            "lower-frequency": "191.3",
                            "upper-frequency": "196.1"
                          }
```

```
                        }
                      ]
                    },
                    {
                      "roadm-path-impairments-set-id": "3",
                      "description": "Add path impairments from LTP 20\
   \ or LTP 30 or LTP 40 to LTP 1 or LTP 2, through AD2",

                      "roadm-add-path": [
                        {
                          "frequency-range-id": 0,
                          "frequency-range": {
                              "lower-frequency": "191.3",
                              "upper-frequency": "196.1"
                          }
                        }
                      ]
                    }
                ]
            }
          },
          "node": [
            {
              "node-id": "example:WDM-TE-Node-1",
              "ietf-te-topology:te-node-id": "192.0.2.1",
              "ietf-te-topology:te": {
                 "te-node-attributes": {
                    "connectivity-matrices": {
                       "connectivity-matrix": [
                          {
                              "id": 1,
                              "from": {
                                 "tp-ref": "example:20"
                              },
                              "to": {
                                 "tp-ref": "example:1",
                                 "ietf-optical-impairment-topology:add\
   \itional-ltp": [
                                    {
                                      "ltp-ref": "example:1",
                                      "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                    },
                                    {
                                      "ltp-ref": "example:2",
                                      "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                    }
```

```
                                  ]
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "2"
                           },
                           {
                               "id": 2,
                               "from": {
                                  "tp-ref": "example:20"
                               },
                               "to": {
                                  "tp-ref": "example:3",
                                  "ietf-optical-impairment-topology:add\
   \itional-ltp": [
                                     {
                                       "ltp-ref": "example:1",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                     },
                                     {
                                       "ltp-ref": "example:2",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                     }
                                  ]
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "2"
                           },
                           {
                               "id": 3,
                               "from": {
                                  "tp-ref": "example:30"
                               },
                               "to": {
                                  "tp-ref": "example:1",
                                  "ietf-optical-impairment-topology:add\
   \itional-ltp": [
                                     {
                                       "ltp-ref": "example:1",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                     },
                                     {
                                       "ltp-ref": "example:2",
                                       "ietf-optical-impairment-topolog\
```

```
   \y:roadm-path-impairments-set": "3"
                                     }
                                  ]
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "2"
                           },
                           {
                               "id": 4,
                               "from": {
                                  "tp-ref": "example:30"
                               },
                               "to": {
                                  "tp-ref": "example:2",
                                  "ietf-optical-impairment-topology:add\
   \itional-ltp": [
                                     {
                                       "ltp-ref": "example:1",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "2"
                                     },
                                     {
                                       "ltp-ref": "example:3",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "2"
                                     }
                                  ]
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "3"
                           },
                           {
                               "id": 5,
                               "from": {
                                  "tp-ref": "example:30"
                               },
                               "to": {
                                  "tp-ref": "example:3",
                                  "ietf-optical-impairment-topology:add\
   \itional-ltp": [
                                     {
                                       "ltp-ref": "example:1",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                     },
                                     {
```

```
                                       "ltp-ref": "example:2",
                                       "ietf-optical-impairment-topolog\
   \y:roadm-path-impairments-set": "3"
                                     }
                                  ]
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "2"
                           },
                           {
                               "id": 6,
                               "from": {
                                  "tp-ref": "example:40"
                               },
                               "to": {
                                  "tp-ref": "example:1"
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "3"
                           },
                           {
                               "id": 7,
                               "from": {
                                  "tp-ref": "example:40"
                               },
                               "to": {
                                  "tp-ref": "example:2"
                               },
                               "is-allowed": true,
                               "ietf-optical-impairment-topology:roadm-\
   \path-impairments-set": "3"
                           }
                        ]
                     }
                  }
               },
               "ietf-network-topology:termination-point": [
                 {
                   "tp-id": "example:20",
                   "ietf-optical-impairment-topology:protection-type": \
   \"ietf-optical-impairment-topology:otsi-protection"
                 },
                 {
                   "tp-id": "example:30",
                   "ietf-optical-impairment-topology:protection-type": \
   \"ietf-optical-impairment-topology:otsi-protection"
```

```
                 },
                 {
                   "tp-id": "example:40"
                 },
                 {
                   "tp-id": "example:1",
                   "ietf-optical-impairment-topology:protection-type": \
   \"ietf-optical-impairment-topology:otsi-protection"
                 },
                 {
                   "tp-id": "example:2",
                   "ietf-optical-impairment-topology:protection-type": \
   \"ietf-optical-impairment-topology:otsi-protection"
                 },
                 {
                   "tp-id": "example:3",
                   "ietf-optical-impairment-topology:protection-type": \
   \"ietf-optical-impairment-topology:otsi-protection"
                 }

               ]

             }
           ]
         }
       ]
     }
   }
```

Appendix C. Optical Transponders in a Remote Shelf (Remote OTs)

Figure 30 illustrates a configuration where the optical transponders and the ROADM are located in a different WDM-TE-nodes.

```
           WDM-TE-node-1                    WDM-TE-node-2
        +----------------+           +--------------------------+
        |     Remote OTs |           |         ROADM            |
        |   +------------+           |     +------------+       |
        |   |            |           | AD  |            |       |
        |   |       +----|           | LTP |            | Line  |
      --o-->|       | Tx o----------->o---->o            | LTP 1 |
        |   | OT 1  +----|           |     |            o-------o<--->
      <-o---|       | Rx o<----------o<----o            |       |
        |   |       +----|           | AD  |            |       |
        |   |            |           | LTP |            |       |
        |   +------------+           |     |            |       |
        |                |           |     |            | Line  |
        |   +------------+           |     |            | LTP 2 |
        |   |            |           | AD  |            o-------o<--->
        |   |       +----|           | LTPs|            |       |
      --o-->|       | Tx o----------->o---->o            |       |
        |   |       +----|           |     |            |       |
      <-o---|       | Rx o<----------o<----o            |       |
        |   | OT 2  +----|           |     |            | Line  |
      --o-->|       | Tx o----------->o---->o            | LTP 3 |
        |   |       +----|           |     |            o-------o<--->
      <-o---|       | Rx o<----------o<----o            |       |
        |   |       +----|           |     |            |       |
        |   |            |           |     |            |       |
        |   +------------+           |     +------------+       |
        |                |           |                          |
        +----------------+           +--------------------------+
```

Figure 30: Optical Transponders in a Remote Shelf (Remote OTs)

As described in Section 2.3, the external shelf can be modeled as WDM-TE-node with termination capability only (not switching) and the add/drop link between a remote optical transceiver and a ROADM add/drop port can be modeled as a WDM TE-link with the same optical impairments as those defined for a WDM TE-link between WDM-TE-nodes (OMS MCG).

If the two WDM-TE-nodes are reported in different network topology instances, the plug-id attribute, defined in [RFC8795], can be used to discover the adjacency for add/drop TE-links.

It is worth noting that there are no standard protocols for automatic discovery of the adjacency between an external transceiver and a ROADM add/drop port and therefore the information reported in the plug-id can be either statically configured or provided through vendor-specific discovery mechanisms.

Each add/drop TE-link carries a single OTSi between the transceiver and ROADM add/drop port and one or more OTSis in the reverse direction (between the ROADM add/drop and the transceiver).

Depending on control architecture (e.g., when the two WDM-TE-nodes are reported in different network topology instances by different controllers), the controller reporting the WDM-TE-node, abstracting the external OT shelf, may be not able to provide the information about the end-to-end MC configuration (i.e.,flexi-n and flexi-m) nor of all the received OTSis, within the end-to-end MC, besides the configured incoming OTSi, since the end-to-end MC configuration depends on how the ROADM network is configured and the remote OT shelf is not aware of that.

In this case only the incoming-otsi and outgoing-otsi can be reported within an end-to-end MC with an unspecified frequency-slot (i.e., without reporting flexi-n and flexi-m configuration of the end-to-end MC).

When an OTSiG has more than one OTSi, its OTSis are carried by different parallel add/drop TE-links. In order to represent the fact that these OTSis are co-routed, the add/drop TE-links are bundled together in a bundled add/drop TE-link. The finest granularity for the bundled add/drop TE-link is the set of all the add/drop TE-links terminating on the same OT.

For example, in Figure 30, it is possible to define two bundled add/drop TE-links, one for OT1 and one for OT2 or just one add/drop TE-link both OTs.

The model for a bundled add/drop TE-link and the relationship with its component TE-links is already defined in the bundled-links container of [RFC8795].

In the general case, the optical impairments and connectivity constraints are reported for each add/drop TE-link and therefore no optical impairments are reported in the bundled add/drop TE-link that is used just to model the co-routing aspects of the OTSis belonging to the same OTSiG.

The per-transceiver Local Link Connectivity (LLC) is used in the WDM-TE-node which abstracts the remote OT shelf (e.g., WDM-TE-node-1 in Figure 30), to represent the association between each transceiver and each LTP terminating the add/drop TE-link which models the transceiver port.

The connectivity matrix in the WDM-TE-node which abstract the edge ROADM (e.g., WDM-TE-node-2 in Figure 30) references the LTPs terminating the add/drop TE-links which models the ROADM add/drop ports.

C.1. JSON Examples for Optical Transponders in a Remote Shelf (Remote OTs)

The JSON example below describes a topology where the optical transponders are located in a remote WDM-TE-node as depicted in Figure 30).

Line-folding as defined in [RFC8792] has been used for the JSON code example below.


```
=============== NOTE: '\\' line wrapping per RFC 8792 ===============

{
  "ietf-network:networks": {
    "network": [
      {
        "network-id": "example:WDM-Network-1",
        "network-types": {
          "ietf-te-topology:te-topology": {
            "ietf-optical-impairment-topology:optical-impairment-top\
\ology": {}
          }
        },
        "ietf-te-topology:te-topology-identifier": {
          "topology-id": "example:WDM-Network-1"
        },
        "ietf-te-topology:te": {},
        "ietf-optical-impairment-topology:otsis": {
          "otsi-group": [
            {
              "otsi-group-id": "Red OTSiG (Forward)",
              "otsi": [
                {
                  "carrier-id": 1
                }
              ]
            },
            {
              "otsi-group-id": "Red OTSiG (Reverse)",
              "otsi": [
                {
                  "carrier-id": 1
                }
```

```
                ]
              },
              {
                "otsi-group-id": "Green OTSiG (Forward)",
                "otsi": [
                  {
                    "carrier-id": 1
                  },
                  {
                    "carrier-id": 2
                  }
                ]
              },
              {
                "otsi-group-id": "Green OTSiG (Reverse)",
                "otsi": [
                  {
                    "carrier-id": 1
                  },
                  {
                    "carrier-id": 2
                  }
                ]
              }
            ]
          },
          "node": [
            {
              "node-id": "example:WDM-TE-Node-1",
              "ietf-te-topology:te-node-id": "192.0.2.1",
              "ietf-te-topology:te": {
                "ietf-te-topology:tunnel-termination-point": [
                  {
                    "tunnel-tp-id": "AQ==",
                    "ietf-optical-impairment-topology:ttp-transceiver"\
   \: [
                      {
                        "transponder-ref": 1,
                        "transceiver-ref": 1
                      }
                    ],
                    "local-link-connectivities": {
                      "is-allowed": false,
                      "local-link-connectivity": [
                        {
                          "link-tp-ref": "example:1",
                          "ietf-optical-impairment-topology:llc-transc\
   \eiver": [
```

```
                              {
                                "ttp-transponder-ref": 1,
                                "ttp-transceiver-ref": 1,
                                "is-allowed": true
                              }
                            ]
                          }
                        ]
                      }
                    },
                    {
                      "tunnel-tp-id": "Ag==",
                      "ietf-optical-impairment-topology:ttp-transceiver"\
   \: [
                        {
                          "transponder-ref": 2,
                          "transceiver-ref": 1
                        },
                        {
                          "transponder-ref": 2,
                          "transceiver-ref": 2
                        }
                      ],
                      "local-link-connectivities": {
                        "is-allowed": false,
                        "local-link-connectivity": [
                          {
                            "link-tp-ref": "example:2",
                            "ietf-optical-impairment-topology:llc-transc\
   \eiver": [
                              {
                                "ttp-transponder-ref": 2,
                                "ttp-transceiver-ref": 1,
                                "is-allowed": true
                              }
                            ]
                          },
                          {
                            "link-tp-ref": "example:3",
                            "ietf-optical-impairment-topology:llc-transc\
   \eiver": [
                              {
                                "ttp-transponder-ref": 2,
                                "ttp-transceiver-ref": 2,
                                "is-allowed": true
                              }
                            ]
                          }
```

```
                      ]
                    }
                  }
                ]
              },
              "ietf-network-topology:termination-point": [
                {
                  "tp-id": "example:1",
                  "ietf-te-topology:te-tp-id": 1,
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "AQ=="
                  }
                },
                {
                  "tp-id": "example:2",
                  "ietf-te-topology:te-tp-id": 2,
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "Ag=="
                  }
                },
                {
                  "tp-id": "example:3",
                  "ietf-te-topology:te-tp-id": 3,
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "Awo="
                  }
                },
                {
                  "tp-id": "example:23",
                  "ietf-te-topology:te-tp-id": 23
                }
              ],
              "ietf-optical-impairment-topology:transponders": {
                "transponder": [
                  {
                    "transponder-id": 1,
                    "transceiver": [
                      {
                        "transceiver-id": 1,
                        "outgoing-otsi": {
                          "otsi-group-ref": "Red OTSiG (Forward)",
                          "otsi-ref": 1
                        },
                        "incoming-otsi": {
                          "otsi-group-ref": "Red OTSiG (Reverse)",
                          "otsi-ref": 1
                        }
                      }
```

```
                  ]
                },
                {
                  "transponder-id": 2,
                  "transceiver": [
                    {
                      "transceiver-id": 1,
                      "outgoing-otsi": {
                        "otsi-group-ref": "Green OTSiG (Forward)",
                        "otsi-ref": 1
                      },
                      "incoming-otsi": {
                        "otsi-group-ref": "Green OTSiG (Reverse)",
                        "otsi-ref": 1
                      }
                    },
                    {
                      "transceiver-id": 2,
                      "outgoing-otsi": {
                        "otsi-group-ref": "Green OTSiG (Forward)",
                        "otsi-ref": 2
                      },
                      "incoming-otsi": {
                        "otsi-group-ref": "Green OTSiG (Reverse)",
                        "otsi-ref": 2
                      }
                    }
                  ]
                }
              ]
            }
          }
        ],
        "ietf-network-topology:link": [
          {
            "link-id": "example:Add-Drop-Link-1-Forward",
            "source": {
              "source-node": "example:WDM-TE-Node-1",
              "source-tp": "example:1"
            },
            "ietf-te-topology:te": {
              "te-link-attributes": {
                "ietf-optical-impairment-topology:oms-attributes": {
                  "media-channel-groups": {
                    "media-channel-group": [
                      {
                        "otsi-group-ref": "Red OTSiG (Forward)",
                        "media-channel": [
```

```
                            {
                              "media-channel-id": 1,
                              "otsi-ref": [
                                {
                                  "carrier-ref": 1
                                }
                              ]
                            }
                          ]
                        }
                      ]
                    }
                  }
                }
              }
            },
            {
              "link-id": "example:Add-Drop-Link-1-Reverse",
              "destination": {
                "dest-node": "example:WDM-TE-Node-1",
                "dest-tp": "example:1"
              },
              "ietf-te-topology:te": {
                "te-link-attributes": {
                  "ietf-optical-impairment-topology:oms-attributes": {
                    "media-channel-groups": {
                      "media-channel-group": [
                        {
                          "otsi-group-ref": "Red OTSiG (Reverse)",
                          "media-channel": [
                            {
                              "media-channel-id": 2,
                              "otsi-ref": [
                                {
                                  "carrier-ref": 1
                                }
                              ]
                            }
                          ]
                        }
                      ]
                    }
                  }
                }
              }
            },
            {
              "link-id": "example:Add-Drop-Link-2-Forward",
```

```
               "source": {
                 "source-node": "example:WDM-TE-Node-1",
                 "source-tp": "example:2"
               },
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "ietf-optical-impairment-topology:oms-attributes": {
                     "media-channel-groups": {
                       "media-channel-group": [
                         {
                           "otsi-group-ref": "Green OTSiG (Forward)",
                           "media-channel": [
                             {
                               "media-channel-id": 2,
                               "otsi-ref": [
                                 {
                                   "carrier-ref": 1
                                 }
                               ]
                             }
                           ]
                         }
                       ]
                     }
                   }
                 }
               }
             },
             {
               "link-id": "example:Add-Drop-Link-2-Reverse",
               "destination": {
                 "dest-node": "example:WDM-TE-Node-1",
                 "dest-tp": "example:2"
               },
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "ietf-optical-impairment-topology:oms-attributes": {
                       "media-channel-groups": {
                         "media-channel-group": [
                           {
                             "otsi-group-ref": "Green OTSiG (Reverse)",
                             "media-channel": [
                               {
                                 "media-channel-id": 3,
                                 "otsi-ref": [
                                   {
                                     "carrier-ref": 1
                                   }
```

```
                            ]
                          }
                        ]
                      }
                    ]
                  }
                }
              }
            }
          },
          {
            "link-id": "example:Add-Drop-Link-3-Forward",
            "source": {
              "source-node": "example:WDM-TE-Node-1",
              "source-tp": "example:3"
            },
            "ietf-te-topology:te": {
              "te-link-attributes": {
                "ietf-optical-impairment-topology:oms-attributes": {
                  "media-channel-groups": {
                    "media-channel-group": [
                      {
                        "otsi-group-ref": "Green OTSiG (Forward)",
                        "media-channel": [
                          {
                            "media-channel-id": 4,
                            "otsi-ref": [
                              {
                                "carrier-ref": 2
                              }
                            ]
                          }
                        ]
                      }
                    ]
                  }
                }
              }
            }
          },
          {
            "link-id": "example:Add-Drop-Link-3-Reverse",
            "destination": {
              "dest-node": "example:WDM-TE-Node-1",
              "dest-tp": "example:3"
            },
            "ietf-te-topology:te": {
              "ietf-te-topology:te-link-attributes": {
```

```
                  "ietf-optical-impairment-topology:oms-attributes": {
                    "media-channel-groups": {
                      "media-channel-group": [
                        {
                          "otsi-group-ref": "Green OTSiG (Reverse)",
                          "media-channel": [
                            {
                              "media-channel-id": 5,
                              "otsi-ref": [
                                {
                                  "carrier-ref": 2
                                }
                              ]
                            }
                          ]
                        }
                      ]
                    }
                  }
                }
              }
            },
            {
              "link-id": "example:Add-Drop-Bundled-Link-Forward",
              "source": {
                "source-node": "example:WDM-TE-Node-1",
                "source-tp": "example:23"
              },
              "ietf-te-topology:te": {
                "bundled-links": {
                  "bundled-link": [
                    {
                      "sequence": 1,
                      "src-tp-ref": "example:2"
                    },
                    {
                      "sequence": 2,
                      "src-tp-ref": "example:3"
                    }
                  ]
                }
              }
            },
            {
              "link-id": "example:Add-Drop-Bundled-Link-Reverse",
              "destination": {
                "dest-node": "example:WDM-TE-Node-1",
                "dest-tp": "example:23"
```

```
              },
              "ietf-te-topology:te": {
                "bundled-links": {
                  "bundled-link": [
                    {
                      "sequence": 1,
                      "des-tp-ref": "example:2"
                    },
                    {
                      "sequence": 2,
                      "des-tp-ref": "example:3"
                    }
                  ]
                }
              }
            }
          ]
        },
        {
          "network-id": "example:WDM-Network-2",
          "network-types": {
            "ietf-te-topology:te-topology": {
              "ietf-optical-impairment-topology:optical-impairment-top\
   \ology": {}
            }
          },
          "ietf-te-topology:te-topology-identifier": {
            "topology-id": "example:WDM-Network-2"
          },
          "ietf-te-topology:te": {},
          "ietf-optical-impairment-topology:otsis": {
            "otsi-group": [
              {
                "otsi-group-id": "Red OTSiG (Forward)",
                "otsi": [
                  {
                    "carrier-id": 1
                  }
                ]
              },
              {
                "otsi-group-id": "Red OTSiG (Reverse)",
                "otsi": [
                  {
                    "carrier-id": 1
                  }
                ]
              },
```

```
              {
                "otsi-group-id": "Green OTSiG (Forward)",
                "otsi": [
                  {
                    "carrier-id": 1
                  },
                  {
                    "carrier-id": 2
                  }
                ]
              },
              {
                "otsi-group-id": "Green OTSiG (Reverse)",
                "otsi": [
                  {
                    "carrier-id": 1
                  },
                  {
                    "carrier-id": 2
                  }
                ]
              }
            ]
          },
          "node": [
            {
              "node-id": "example:WDM-TE-Node-2",
              "ietf-te-topology:te-node-id": "192.0.2.2",
              "ietf-te-topology:te": {},
              "ietf-network-topology:termination-point": [
                {
                  "tp-id": "example:1",
                  "ietf-te-topology:te-tp-id": 1,
                  "ietf-te-topology:te": {}
                },
                {
                  "tp-id": "example:2",
                  "ietf-te-topology:te-tp-id": 2,
                  "ietf-te-topology:te": {}
                },
                {
                  "tp-id": "example:3",
                  "ietf-te-topology:te-tp-id": 3,
                  "ietf-te-topology:te": {}
                },
                {
                  "tp-id": "example:4",
                  "ietf-te-topology:te-tp-id": 4,
```

```
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "AQ=="
                  }
                },
                {
                  "tp-id": "example:5",
                  "ietf-te-topology:te-tp-id": 5,
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "Ag=="
                  }
                },
                {
                  "tp-id": "example:6",
                  "ietf-te-topology:te-tp-id": 6,
                  "ietf-te-topology:te": {
                    "inter-domain-plug-id": "Awo="
                  }
                }
              ]
            }
          ],
          "ietf-network-topology:link": [
            {
              "link-id": "example:Add-Drop-Link-1-Forward",
              "destination": {
                "dest-node": "example:WDM-TE-Node-2",
                "dest-tp": "example:4"
              },
              "ietf-te-topology:te": {
                "te-link-attributes": {
                  "ietf-optical-impairment-topology:oms-attributes": {
                    "media-channel-groups": {
                      "media-channel-group": [
                        {
                          "otsi-group-ref": "Red OTSiG (Forward)",    \
   \
                          "media-channel": [
                            {
                              "media-channel-id": -10,
                              "flexi-n": -10,
                              "otsi-ref": [
                                {
                                  "carrier-ref": 1
                                }
                              ]
                            }
                          ]
                        }
```

```
                       ]
                     }
                   }
                 }
               }
             },
             {
               "link-id": "example:Add-Drop-Link-1-Reverse",
               "source": {
                 "source-node": "example:WDM-TE-Node-2",
                 "source-tp": "example:4"
               },
               "ietf-te-topology:te": {
                 "te-link-attributes": {
                   "ietf-optical-impairment-topology:oms-attributes": {
                     "media-channel-groups": {
                       "media-channel-group": [
                         {
                           "otsi-group-ref": "Red OTSiG (Reverse)",
                           "media-channel": [
                             {
                               "media-channel-id": 10,
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                                 {
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                               ]
                             }
                           ]
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                               ]
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                         }
```

```
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                }
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          },
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                                  "carrier-ref": 2
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                  }
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            },
            {
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                "dest-tp": "example:6"
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                }
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                      "carrier-id": 2
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                }
              ]
            },
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                              "ttp-transceiver-ref": 1,
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                            }
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                        }
                      ]
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                        "transceiver-ref": 2
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                              "ttp-transceiver-ref": 2,
                              "is-allowed": true
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              }
            ]
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              "ietf-te-topology:te-tp-id": 1,
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            },
            {
              "tp-id": "example:2",
              "ietf-te-topology:te-tp-id": 2,
              "ietf-te-topology:te": {}
            },
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              "ietf-te-topology:te-tp-id": 3,
              "ietf-te-topology:te": {}
            },
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              "tp-id": "example:23",
              "ietf-te-topology:te-tp-id": 23
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                "transceiver": [
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                      "otsi-ref": 1
                    },
                    "incoming-otsi": {
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                      "otsi-ref": 1
                    }
                  }
                ]
              },
              {
                "transponder-id": 2,
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                          "otsi-ref": 1
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                        "incoming-otsi": {
                          "otsi-group-ref": "Green OTSiG (Reverse)",
                          "otsi-ref": 1
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                      },
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                          "otsi-group-ref": "Green OTSiG (Forward)",
                          "otsi-ref": 2
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                        "incoming-otsi": {
                          "otsi-group-ref": "Green OTSiG (Reverse)",
                          "otsi-ref": 2
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                      }
                    ]
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                ]
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            {
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              "ietf-te-topology:te-node-id": "192.0.2.2",
              "ietf-te-topology:te": {},
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                  "ietf-te-topology:te-tp-id": 1,
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                {
                  "tp-id": "example:2",
                  "ietf-te-topology:te-tp-id": 2,
                  "ietf-te-topology:te": {}
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                {
                  "tp-id": "example:3",
                  "ietf-te-topology:te-tp-id": 3,
                  "ietf-te-topology:te": {}
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                  "ietf-te-topology:te": {}
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                },
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                },
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              "source": {
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                "source-tp": "example:1"
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                "dest-tp": "example:4"
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                                  "carrier-ref": 1
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                        ]
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                    ]
                  }
                }
              }
            }
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                          }
                        ]
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                      {
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                    }
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                              ]
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                              ]
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                          ]
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            }
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                        "flexi-n": -20,
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                        ]
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```

```
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```

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