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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 WSON, while it is known as Impairment-Aware Routing and Spectrum Assigment (IA-RSA) for SSON.

This document provides a YANG data model for the impairment-aware TE topology in optical networks.

Status of This Memo

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1. Introduction

In order to provision an optical connection (an optical path) through a wavelength switched optical networks (WSONs) 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.

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, which can be utilized by a Multi-Domain Service Coordinator (MDSC) to collect states of WSON impairment data from the Transport PNCs to enable impairment-aware optical path computation according to the ACTN Architecture [RFC8453]. The communication between controllers is done via a NETCONF [RFC8341] or a RESTCONF [RFC8040]. Similarly,this model can also be exported by the MDSC to a Customer Network Controller (CNC), which can run an offline planning process to map latter the services in the network.

It is worth noting that optical data plane interoperability is a complex topic especially in a multi vendor environment and usually requires joint engineering, which is independent from control plane and management plane capabilities. The YANG data model defined in this draft is providing sufficient information to enable optical impairment aware path computation.
Optical data plane interoperability is outside the scope of this draft.

This document augments the generic TE topology draft [RFC8795] where possible.

This document defines one YANG module: ietf-optical-impairment-topology (Section 3) according to the new Network Management Datastore Architecture [RFC8342].

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:

- o client
- o server
- o augment
- o data model
- o data node

The following terms are defined in [RFC6241] and are not redefined here:

- o configuration data
- o state data

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

1.2. Tree Diagram

A simplified graphical representation of the data model is used in Section 2 of this 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
optical-imp-topo	ietf-optical-impairment-topology	[RFCXXXX]
layer0-types	ietf-layer0-types	[I-D.ietf-ccamp-layer0-types]
l0-types-ext	ietf-layer0-types-ext	[I-D.esdih-ccamp-layer0-types-ext]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[RFC8795]

Table 1: Prefixes and corresponding YANG modules

[Editor's note: The RFC Editor will replace XXXX with the number assigned to the RFC once this draft becomes an RFC.]

2. Reference Architecture

2.1. Control Plane Architecture

Figure 1 shows the control plane architecture.

```
                             +--------+
                             |  MDSC  |
                             +--------+
    Scope of this ID  ------->   ||
                  |              ||
                  |  +------------------------+
                  |  |        OPTICAL         |
     +---------+  |  |         DOMAIN         |     +---------+
     | Device  |  |  |       CONTROLLER       |     | Device  |
     | config. |  |  +------------------------+     | config. |
     +---------+  v  //          ||          \\     +---------+
    ______|______   //           ||           \\   ______|______
   /      OT     \ //            ||            \\ /      OT     \
   | +--------+  |//           __--__           \\|  +--------+ |
   | |Vend. A |--|----+       (      )       +----|--| Vend. A| |
   | +--------+  |    |    ~-(        )-~    |    |  +--------+ |
   | +--------+  |    +---/              \---+    |  +--------+ |
   | |Vend. B |--|--+    /                \    +--|--| Vend. B| |
   | +--------+  |  +---(   OLS Segment    )---+  |  +--------+ |
   | +--------+  |  +---(                  )---+  |  +--------+ |
   | |Vend. C |--|--+    \                /    +--|--| Vend. C| |
   | +--------+  |    +---\              /---+    |  +--------+ |
   | +--------+  |    |    ~-(        )-~    |    |  +--------+ |
   | |Vend. D |--|----+       (__  __)       +----|--| Vend. D| |
   | +--------+  |               --               |  +--------+ |
   \_____________/                                \_____________/
             ^                                        ^
             |                                        |
             |                                        |
            Scope of [I-D.ietf-ccamp-dwdm-if-param-yang]
```

Figure 1: Scope of draft-ietf-ccamp-dwdm-if-param-yang

The models developed in this document is an abstracted YANG model that may be used in the interfaces between the MDSC and the Optical Domain Controller (aka MPI) and between the Optical Domain Controller and the Optical Device (aka SBI) in Figure 1. It is not intended to support a detailed low-level DWDM interface model. DWDM interface model is supported by the models presented in [I-D.ietf-ccamp-dwdm-if-param-yang].

2.2. Transport Data Plane

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

Figure 2 shows the reference architecture.

```
  +--------------------+                      +--------------------+
  |     ROADM Node     |                      |     ROADM Node     |
  |                    |                      |                    |
  | PA  +--------+ BA  |         ILA          | PA  +--------+ BA  |
  | +-+ | WSS/   | +-+ |  _____  +--+  _____  | +-+ |  WSS/  | +-+ |
--|-| |-|Filter |-| |-|-()____)-|  |-()____)-|-| |-|Filter |-| |-|--
  | +-+ |        | +-+ |         +--+         | +-+ |        | +-+ |
  |     +--------+     | optical              |     +--------+     |
  |       | | |        |  fiber               |       | | |        |
  |       o o o        |                      |       o o o        |
  |    transponders    |                      |    transponders    |
  +--------------------+                      +--------------------+
                     OTS Link       OTS Link
                    <---------->   <---------->
                                OMS Link
                <---------------------------------->
```

PA: Pre-Amplifieror
BA: Booster Amplifier
ILA: In-Line Amplifier

Figure 2: Reference Architecture for Optical Transport Network

BA (on the left side ROADM) is the ingress Amplifier and PA (on the right side ROADM is the egress amplifier for the OMS link shown in Figure 2.

2.3. OMS Media Links

According to [G.872], OMS Media Link represents a media link between two ROADMs. Specifically, it originates at the ROADM's Filter in the source ROADM and terminates at the ROADM's Filter in the destination ROADM.

OTS Media Link represents a media link:

  (i) between ROADM's BA and ILA;
 (ii) between a pair of ILAs;
(iii) between ILA and ROADM's PA.

OMS Media link can be decomposed in a sequence of OTS links type (i), (ii), and (iii) as discussed above. OMS Media link would give an abstracted view of impairment data (e.g., power, OSNR, etc.) to the network controller.

For the sake of optical impairment evaluation OMS Media link can be also decomposed in a sequence of elements such as BA, fiber section, ILA, concentrated loss and PA.

[Editor's note: text below related to [G.807] needs to be revised! [G.807] is now in publication process.]

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]. The YANG model defined below 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.

2.3.2. Optical Tributary Signal Group (OTSiG)

The definition of the OTSiG is currently being moved from ITU-T Recommendation G.709 [G.709] to the new draft Recommendation G.807 (still work in progress) [G.807]. The OTSiG is an electrical signal that is carried by one or more OTSi's. The relationship between the OTSiG and the the OTSi's is described in ITU-T draft Recommendation G.807, section 10.2 [G.807]. The YANG model below supports both cases: the single OTSi case where the OTSiG contains a single OTSi (see ITU-T draft Recommendation G.807, Figure 10-2) and the multiple OTSi case where the OTSiG consists of more than one OTSi (see ITU-T draft Recommendation 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.

```
                                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
                  K1           K2           K3           K4
```

Figure 3: MC Example containing all 4 OTSi signals of an OTSiG

2.3.3. Media Channel (MC)

The definition of the MC is currently being moved from ITU-T Recommendation G.872 [G.872] to the new draft Recommendation G.807 (still work in progress) [G.807]. Section 3.2.2 defines the term MC and section 7.1.2 provides a more detailed description with some examples. The definition of the MC is very generic (see ITU-T draft Recommendation G.807, Figure 7-1). In the YANG model below, the MC is used with the following semantics:

The MC is an end-to-end topological network construct and can be considered as an "optical pipe" with a well-defined frequency slot between one or more optical transmitters each generating an OTSi and the corresponding optical receivers terminating the OTSi's. If the MC carries more than one OTSi, it is assumed that these OTSi's belong to the same OTSiG.

```
                                    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             |
                      K1                            K2

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

Figure 4: Figure Caption TBA

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 ITU-T Recommendation G.694.1 [G.694.1]. In this model, the effective frequency slot as defined in ITU-T draft Recommendation G.807 is equal to the frequency slot of this end-to-end 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)

The definition of the MCG is currently work in progress in ITU-T and is defined in section 7.1.3 of the new ITU-T draft Recommendation G.807 (still work in progress) [G.807]. The YANG model below assumes that the MCG is a logical grouping of one or more MCs that are used to 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 have to 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 5: Figure Caption TBA

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

2.4. Amplifiers

Optical amplifiers are in charge of amplifying the optical signal in the optical itself without any electrical conversion. There are three main technologies to build amplifiers: Erbium Doped Fiber Amplifier (EDFA), Raman Fiber Amplifier (RFA), and Semiconductor Optical Amplifier (SOA). Nowadays, most of optical networks uses EDFAs. However, RFA has an attractive feature that it works in any wavelength band with a similar or lower noise figures compared to EDFA. On the other hand, RFAs consumes more power and are more expensive than EDFAs.

Amplifiers can be classified according to their location in the communication link. There are three basic types of amplifiers: ILA, Pre-Amplifier and Booster. ILA is In-Line Amplifier which is a separate node type while Pre-Amplifier and Booster Amplifier are integral elements of ROADM node. From a data modeling perspective, Pre-Amplifier and Booster Amplifier are internal functions of a ROADM node and as such these elements are hidden within ROADM node. In this document, we would avoid internal node details, but attempt to abstract as much as possible.

One modeling consideration of the ROADM internal is to model power parameter through the ROADM, factoring the output power from the Pre-Amplifier minus the ROADM power loss would give the input power to the Booster Amplifier. In other words, Power_in (@ ROADM Booster) = Power_out (@ ROADM Pre-Amplifier) - Power_loss (@ ROADM WSS/Filter).

2.5. Transponders

[Editor's note: The relationship between the transponder and the OTSi in the YANG model described in Section 3 needs further clarification and refinement.]

A Transponder is the element that sends and receives the optical signal from a DWDM network. A transponder can comprise one or more transceivers. A transceiver can be seen as a pair of transmitter and receiver, as defined in ITU-T Recommendation G.698.2 [G.698.2].

A transponder is typically characterized by its data/symbol rate and the maximum distance the signal can travel. Other transponder properties are: carrier frequency for the optical channels, output power per channel, measured input power, modulation scheme, 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

2.5.1. Standard Modes

A standard mode is related to an optical specification developed by an SDO organization. Currently, the "Standard Modes" can only be referred to ITU-T G.698.2 [G.698.2] since G.698.2 is the only specification defining "Standard Modes" today. Nothing is precluding, however, to consider other specifications provided by any other SDO in the Standard Mode context as soon as such sepcifications will be available. An application code as defined in ITU-T G.698.2 [G.698.2] is representing a standard ITU-T G.698.2 optical interface specification towards the realization of transversely compatible DWDM systems. 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.

2.5.2. 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 anoperational 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 shall 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 shall, however, only be an done in exceptional cases and shall 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.

2.5.3. Explicit Modes

The explicit mode allows to encode, explicitly, 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 draft. 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.

2.5.4. 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 above (choice in the YANG model). The YANG model allows to describe 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 transmitter tunability grid, the 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 OSNR, max PMD, max CD, max PDL, Q-factor limit, are explicitly defined for the explicit modes while they are defined implicitly for the application codes and organizational modes.

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 "supported-mode" 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:

- o Pointer to the transponder instance containing the transceiver terminating the OTSi
- o Pointer to the transceiver instance terminating the OTSi
- o Pointer to the currently configured transceiver mode

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

- o current carrier-frequency
- o currently transmitted channel power
- o currently received channel power
- o currently received total power

2.6. 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 regeneartion 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 provided functionality, 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 2.5 above. 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:

o 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

o 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 an uni-directional mode.

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


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

                     Sig. Proc. = Signal Processing
```

Figure 7: Cross-3R Regenerator Example

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

- o supported-termination-type
- o 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 attrbute describes the configuration of the transponder pair forming the 3R regeneartor as described above.

More text to be added here!

2.7. WSS/Filter

WSS separates the incoming light input spectrally as well as spatially, then chooses the wavelength that is of interest by deflecting it from the original optical path and then couple it to another optical fibre port. WSS/Filter is internal to ROADM. So this document does not model the inside of ROADM.

2.8. Optical Fiber

There are various optical fiber types defined by ITU-T. There are several fiber-level parameters that need to be factored in, such as, fiber-type, length, loss coefficient, pmd, connectors (in/out).

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.

2.9. ROADM Node Architectures

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

- o Integrated ROADM architecture with integrated optical transponders

- o Integrated ROADM architecture with integrated optical transponders and single channel add/drop ports for remote optical transponders

- o Disaggregated ROADM architecture where the ROADM is subdivided into degree, add/drop, and optical transponder subsystems handled as separate network elements

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

The different ROADM architectures are briefly described and illustrated in the following subsections.

[Editor's note: The modeling of remote optical transponders located for example in the client device with a single channel link between the OT and the add/drop port of the ROADM requires further investigations and will be addressed in a future revision of this document.]

2.9.1. Integrated ROADM Architecture with Integrated Optical Transponders

Figure 2 and Figure 8 below show the typical architecture of an integrated ROADM node, which contains the optical transponders as an integral part of the ROADM node. Such an integrated ROADM node provides DWDM interfaces as external interfaces for interconnecting the device with its neighboring ROADMs (see OTS link above). The number of these interfaces denote also the degree of the ROADM. A degree 3 ROADM for example has 3 DWDM links that interconnect the ROADM node with 3 neighboring ROADMs. Additionally, the ROADM provides client interfaces for interconnecting the ROADM with client devices such as IP routers or Ethernet switches. These client interfaces are the client interfaces of the integrated optical transponders.

```
               . . . . . . . . . . . . . . . . . .
         +-----.-------------------------------- .-----+
         |     .              ROADM              .     |
         |     .   /|  +-----------------+  |\   .     |
    Line |     .  / |--|                 |--| \  .     | Line
    WEST |  /| . |  |--|                 |--|  | . |\  | EAST
   ------+-/ |-.-|  |--|       OCX       |--|  |-.-| \-+------
   ------+-\ |-.-|  |--|                 |--|  |-.-| /-+------
         |  \| . |  |--|                 |--|  | . |/  |
         |     .  \ |--|                 |--| /  .     |
         |     .   \|  +-----------------+  |/   .     |
         |     .                                 .     |
         |     .     +---+ +---+ +---+ +---+     .     |
         |     .     | O | | O | | O | | O |     .     |
         |     .     | T | | T | | T | | T |     .     |
         |     .     +---+ +---+ +---+ +---+     .     |
         |     .      | |   | |   | |   | |      .     |
         +-----.------+-+---+-+---+-+---+-+------.-----+
               . . . .|.| . |.| . |.| . |.|. . . .
                      | |   | |   | |   | |     TE Node
                        Client Interfaces
```

Figure 8: ROADM Architectiure with Integrated Transponders

2.9.2. **Integrated ROADMs 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 ROADM but are separate devices that are interconnected with add/drop ports of the ROADM. If the optical transponders and the ROADM are collocated and if short single channel fiber links are used to interconnect the optical transponders with an add/drop port of the ROADM, the optical domain controller may present these optical transponders in the same way as integrated optical transponders. If, however, the optical impairments of the single channel fiber link between the optical transponder and the add/drop port of the ROADM 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

[Editor's note: this requires further study].

```
            . . . . . . . . . . . . . . . . . .
            .       Abstracted ROADM          .
      +-----.-------------------------------- .-----+
      |     .              ROADM              .     |
      |     .   /|  +-----------------+  |\   .     |
 Line |     .  / |--|                 |--| \  .     | Line
 WEST |  /| . |  |--|                 |--|  | . |\  | EAST
------+-/ |-.-|  |--|       OCX       |--|  |-.-| \-+-----
------+-\ |-.-|  |--|                 |--|  |-.-| /-+-----
      |  \| . |  |--|                 |--|  | . |/  |
      |     .  \ |--|                 |--| /  .     |
      |     .   \|  +-----------------+  |/   .     |
      +-----.---------|----|---|----|---------.-----|
 Colored OT .       +-+   ++   ++   +-+       .
 line I/F   .       |     |     |     |       .
            .     +---+ +---+ +---+ +---+     .
            .     | O | | O | | O | | O |     .
            .     | T | | T | | T | | T |     .
            .     +---+ +---+ +---+ +---+     .
            . . . .|.| . |.| . |.| . |.|. . . .
                   | |   | |   | |   | |     TE Node
                     Client Interfaces
```

Figure 9: ROADM Architectiure with Remote Transponders

2.9.3. Disaggregated ROADMs Subdivided into Degree, Add/Drop, and Optical Transponder Subsystems

Recently, some DWDM network operators started demanding ROADM subsystems from their vendors. An example is the OpenROADM project where multiple operators and vendors are developing related YANG models. The subsystems of a disaggregated ROADM are: single degree subsystems, add/drop subsystems and optical transponder subsystems. These subsystems 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 ROADM node. This disaggregated ROADM architecture is depicted in Figure 10 below.

As this document defines TE topology YANG model augmentations [RFC8795] for the TE topology YANG model 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 ROADM and presents the disaggregated ROADM in the same way as an integrated ROADM hiding all the interconnects that are not relevant from an external TE topology view.

```
              . . . . . . . . . . . . . . . . . .
              .        Abstracted ROADM          .
        +-----.----------+            +----------.-----+
        | 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 |   .
                .   +---+ +---+ +---+ +---+   .
                . . .|.| . |.| . |.| . |.|. . .
                     | |   | |   | |   | |     TE Node
                       Client Interfaces
```

Figure 10: Disaggregated ROADM Architecture with Remote Transponders

2.9.4. Optical Impairments Imposed by ROADM 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:

- o Chromatic dispersion (CD)
- o Polarization mode dispersion (PMD)
- o Polarization dependent loss (PDL)

- Optical amplifier noise due to amplified spontaneous emission (ASE)
- In-band cross-talk
- Filtering effects (for further study)

A ROADM node contains a wavelength selective photonic switching function (WSS)that is capable of switching 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, this is a single channel signal (single OTSi), but principally this could also be a group of OTSi signals. 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 have to be modeled separately.

The optical impairments associated with each of the three types of ROADM-node-internal paths described 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, which are included in the optical impairment parameter sets (see tree view in Section 3).

[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).

[Editor's note: this section is still work in progress]

3. YANG Model (Tree Structure)

[Editor's note: tree view below always has to be updated before submitting a new revision!]

```
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/nw:node:
    +--ro transponder* [transponder-id]
       +--ro transponder-id    uint32
       +--ro transceiver* [transceiver-id]
          +--ro transceiver-id                   uint32
          +--ro termination-type-capabilities?   enumeration
          +--ro supported-3r-mode?               enumeration
          +--ro configured-termination-type?     enumeration
          +--ro supported-modes
             +--ro supported-mode* [mode-id]
                +--ro mode-id                      string
                +--ro (mode)
                   +--:(G.698.2)
                   |  +--ro standard-mode?         standard-mode
                   +--:(organizational-mode)
                   |  +--ro organizational-mode
                   |     +--ro operational-mode?
                   |     |       operational-mode
                   |     +--ro organization-identifier?
                   |     |       organization-identifier
                   |     +--ro min-central-frequency?
                   |     |       frequency-thz
                   |     +--ro max-central-frequency?
                   |     |       frequency-thz
                   |     +--ro minimum-channel-spacing?
                   |     |       frequency-ghz
                   |     +--ro tx-channel-power-min?      dbm-t
                   |     +--ro tx-channel-power-max?      dbm-t
                   |     +--ro rx-channel-power-min?      dbm-t
                   |     +--ro rx-channel-power-max?      dbm-t
                   |     +--ro rx-total-power-max?        dbm-t
```

```
                   +--:(explicit-mode)
                      +--ro explicit-mode
                         +--ro supported-modes
                         |  +--ro supported-application-codes*
                         |  |       -> ../../../mode-id
                         |  +--ro supported-organizational-modes*
                         |          -> ../../../mode-id
                         +--ro line-coding-bitrate?
                         |       identityref
                         +--ro max-polarization-mode-dispersion?
                         |       decimal64
                         +--ro max-chromatic-dispersion?
                         |       decimal64
                         +--ro chromatic-and-polarization-dispersion-penalty*
[]
                         |  +--ro chromatic-dispersion
                         |  |       decimal64
                         |  +--ro polarization-mode-dispersion
                         |  |       decimal64
                         |  +--ro penalty
                         |          decimal64
                         +--ro max-diff-group-delay?
                         |       int32
                         +--ro max-polarization-dependent-loss-penalty* []
                         |  +--ro max-polarization-dependent-loss
                         |  |       decimal64
                         |  +--ro penalty
                         |          uint8
                         +--ro available-modulation-type?
                         |       identityref
                         +--ro otsi-carrier-bandwidth?
                         |       frequency-ghz
                         +--ro min-OSNR?
                         |       snr
                         +--ro min-Q-factor?
                         |       int32
                         +--ro available-baud-rate?
                         |       uint32
                         +--ro nyquist-spacing-factor?
                         |       decimal64
                         +--ro roll-off?
                         |       decimal64
                         +--ro xtalk-penalty?
                         |       int32
                         +--ro available-fec-type?
                         |       identityref
                         +--ro fec-code-rate?
                         |       decimal64
```

```
                    +--ro fec-threshold?
```

```
                         |       decimal64
                         +--ro min-central-frequency?
                         |       frequency-thz
                         +--ro max-central-frequency?
                         |       frequency-thz
                         +--ro minimum-channel-spacing?
                         |       frequency-ghz
                         +--ro tx-channel-power-min?
                         |       dbm-t
                         +--ro tx-channel-power-max?
                         |       dbm-t
                         +--ro rx-channel-power-min?
                         |       dbm-t
                         +--ro rx-channel-power-max?
                         |       dbm-t
                         +--ro rx-total-power-max?
                                 dbm-t
  augment /nw:networks/nw:network/nt:link/tet:te
            /tet:te-link-attributes:
    +--ro OMS-attributes
       +--ro generalized-snr?                       l0-types-ext:snr
       +--ro equalization-mode                      identityref
       +--ro (power-param)?
       |  +--:(channel-power)
       |  |  +--ro nominal-carrier-power?           decimal64
       |  +--:(power-spectral-density)
       |     +--ro nominal-power-spectral-density?   decimal64
       +--ro media-channel-group* [i]
       |  +--ro i                  int16
       |  +--ro media-channels* [flexi-n]
       |     +--ro flexi-n           l0-types:flexi-n
       |     +--ro flexi-m?          l0-types:flexi-m
       |     +--ro otsi-group-ref?   leafref
       |     +--ro otsi-ref?         leafref
       |     +--ro delta-power?      decimal64
       +--ro OMS-elements* [elt-index]
          +--ro elt-index                uint16
          +--ro oms-element-uid?         string
          +--ro (element)
             +--:(amplifier)
             |  +--ro amplifier
             |     +--ro type-variety    string
             |     +--ro operational
             |        +--ro amplifier-element* []
             |           +--ro name?
             |           |       string
             |           +--ro frequency-range
             |           |  +--ro lower-frequency    frequency-thz
```

```
             |           |  +--ro upper-frequency    frequency-thz
             |           +--ro actual-gain
             |           |       decimal64
             |           +--ro tilt-target
             |           |       decimal64
             |           +--ro out-voa
             |           |       decimal64
             |           +--ro in-voa
             |           |       decimal64
             |           +--ro (power-param)?
             |              +--:(channel-power)
             |              |  +--ro nominal-carrier-power?
             |              |          decimal64
             |              +--:(power-spectral-density)
             |                 +--ro nominal-power-spectral-density?
             |                         decimal64
             +--:(fiber)
             |  +--ro fiber
             |     +--ro type-variety    string
             |     +--ro length          decimal64
             |     +--ro loss-coef       decimal64
             |     +--ro total-loss      decimal64
             |     +--ro pmd?            decimal64
             |     +--ro conn-in?        decimal64
             |     +--ro conn-out?       decimal64
             +--:(concentratedloss)
                +--ro concentratedloss
                   +--ro loss    decimal64
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:tunnel-termination-point:
    +--ro otsi-group* [otsi-group-id]
    |  +--ro otsi-group-id    int16
    |  +--ro otsi* [otsi-carrier-id]
    |     +--ro otsi-carrier-id           int16
    |     +--ro transponder-ref?
    |     |       -> ../../../../../transponder/transponder-id
    |     +--ro transceiver-ref?          leafref
    |     +--ro configured-mode?          leafref
    |     +--ro otsi-carrier-frequency?   frequency-thz
    |     +--ro tx-channel-power?         dbm-t
    |     +--ro rx-channel-power?         dbm-t
    |     +--ro rx-total-power?           dbm-t
    +--ro transceiver* []
       +--ro transponder-ref?
       |       -> ../../../../transponder/transponder-id
       +--ro tranceiver-ref?    leafref
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:tunnel-termination-point:
```

```
    +--ro sliceable-transponder-list* [carrier-id]
       +--ro carrier-id    uint32
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:te-node-attributes:
    +--ro roadm-path-impairments* [roadm-path-impairments-id]
       +--ro roadm-path-impairments-id    uint32
       +--ro (impairment-type)?
          +--:(roadm-express-path)
          |  +--ro roadm-express-path* []
          |     +--ro frequency-range
          |     |  +--ro lower-frequency    frequency-thz
          |     |  +--ro upper-frequency    frequency-thz
          |     +--ro roadm-pmd?                decimal64
          |     +--ro roadm-cd?                 decimal64
          |     +--ro roadm-pdl?                decimal64
          |     +--ro roadm-inband-crosstalk?   decimal64
          |     +--ro roadm-maxloss?            decimal64
          +--:(roadm-add-path)
          |  +--ro roadm-add-path* []
          |     +--ro frequency-range
          |     |  +--ro lower-frequency    frequency-thz
          |     |  +--ro upper-frequency    frequency-thz
          |     +--ro roadm-pmd?                decimal64
          |     +--ro roadm-cd?                 decimal64
          |     +--ro roadm-pdl?                decimal64
          |     +--ro roadm-inband-crosstalk?   decimal64
          |     +--ro roadm-maxloss?            decimal64
          |     +--ro roadm-pmax?               decimal64
          |     +--ro roadm-osnr?               l0-types-ext:snr
          |     +--ro roadm-noise-figure?       decimal64
          +--:(roadm-drop-path)
             +--ro roadm-drop-path* []
                +--ro frequency-range
                |  +--ro lower-frequency    frequency-thz
                |  +--ro upper-frequency    frequency-thz
                +--ro roadm-pmd?                decimal64
                +--ro roadm-cd?                 decimal64
                +--ro roadm-pdl?                decimal64
                +--ro roadm-inband-crosstalk?   decimal64
                +--ro roadm-maxloss?            decimal64
                +--ro roadm-minloss?            decimal64
                +--ro roadm-typloss?            decimal64
                +--ro roadm-pmin?               decimal64
                +--ro roadm-pmax?               decimal64
                +--ro roadm-ptyp?               decimal64
                +--ro roadm-osnr?               l0-types-ext:snr
                +--ro roadm-noise-figure?       decimal64
  augment /nw:networks/nw:network/nw:node/tet:te
```

```
            /tet:information-source-entry/tet:connectivity-matrices:
    +--ro roadm-path-impairments?   leafref
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:information-source-entry/tet:connectivity-matrices
            /tet:connectivity-matrix:
    +--ro roadm-path-impairments?   leafref
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:te-node-attributes/tet:connectivity-matrices:
    +--ro roadm-path-impairments?
            -> ../../roadm-path-impairments/roadm-path-impairments-id
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:te-node-attributes/tet:connectivity-matrices
            /tet:connectivity-matrix:
    +--ro roadm-path-impairments?   leafref
  augment /nw:networks/nw:network/nw:node/tet:te
            /tet:tunnel-termination-point
            /tet:local-link-connectivities:
    +--ro add-path-impairments?    leafref
    +--ro drop-path-impairments?   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?    leafref
    +--ro drop-path-impairments?   leafref
```

4. Optical Impairment Topology YANG Model

[Editor's note: YANG code below always has to be updated before submitting a new revision!]

```
<CODE BEGINS>
module ietf-optical-impairment-topology {
  yang-version 1.1;

  namespace "urn:ietf:params:xml"
  +":ns:yang:ietf-optical-impairment-topology";

  prefix "optical-imp-topo";

  import ietf-network {
    prefix "nw";
  }

  import ietf-network-topology {
    prefix "nt";
  }
```

```
     import ietf-te-topology {
       prefix "tet";
     }

     import ietf-layer0-types {
       prefix "l0-types";
     }

     import ietf-layer0-types-ext {
       prefix "l0-types-ext";
     }

     organization
       "IETF CCAMP Working Group";

     contact
       "Editor:   Young Lee <younglee.tx@gmail.com>
        Editor:   Haomian Zheng <zhenghaomian@huawei.com>
        Editor:   Nicola Sambo <nicosambo@gmail.com>
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        Editor:   Gabriele Galimberti <ggalimbe@cisco.com>
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        Editor:   Sergio Belotti <Sergio.belotti@nokia.com>
        Editor:   Griseri Enrico <enrico.griseri@nokia.com>
        Editor:   Gert Grammel <ggrammel@juniper.net>";

     description
       "This module contains a collection of YANG definitions for
        impairment-aware optical networks.

        Copyright (c) 2021 IETF Trust and the persons identified as
        authors of the code.  All rights reserved.

        Redistribution and use in source and binary forms, with or
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        Provisions Relating to IETF Documents
        (http://trustee.ietf.org/license-info).
        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 2021-07-05 {
       description
         "Initial Version";
       reference
         "RFC XXXX: A Yang Data Model for Impairment-aware
          Optical Networks";
     }

     // grouping

     grouping transponder-attributes {
       description "Configuration of an optical transponder";

       leaf-list available-modulation-types {
         type identityref {
         base l0-types-ext:modulation;
         }
         config false;
       description
         "List of modulation types the OTSi supports";
       }

       leaf configured-modulation-type {
         type identityref {
         base l0-types-ext:modulation;
         }
       config false;
         description
         "Currently configured OTSi modulation type";
       }

       leaf-list available-baud-rates {
         type uint32;
           units Bd;
         config false;
         description
           "list of available baud-rates.
            Baud-rate is the unit for
            symbol rate or modulation rate
            in symbols per second or
            pulses per second.
            It is the number of distinct symbol
```

```
             changes (signal events) made to the
             transmission medium
             per second in a digitally
             modulated signal or a line code";
        }

        leaf configured-baud-rate {
          type uint32;
          units Bd;
        config false;
          description "configured baud-rate";
        }

        leaf-list available-FEC-types {
          type identityref {
          base l0-types-ext:fec-type;
          }
          config false;
          description "List determining all the available FEC";
        }

        leaf configured-FEC-type {
          type identityref {
          base l0-types-ext:fec-type;
          }
          config false;
        description
          "FEC type configured for the transponder";
        }

        leaf FEC-code-rate {
          type decimal64 {
          fraction-digits 8;
          range "0..max";
          }
          config false;
          description "FEC-code-rate";
        }

        leaf FEC-threshold {
          type decimal64 {
          fraction-digits 8;
          range "0..max";
          }
          config false;
        description
            "Threshold on the BER, for which FEC
             is able to correct errors";
```

```
       }

     }

     grouping sliceable-transponder-attributes {
       description
         "Configuration of a sliceable transponder.";
       list sliceable-transponder-list {
         key "carrier-id";
         config false;
         description "List of carriers";
         leaf carrier-id {
           type uint32;
           config false;
           description "Identifier of the carrier";
         }
       }
     }

     grouping optical-fiber-data {
       description
       "optical link (fiber) attributes with impairment data";
       leaf fiber-type {
         type l0-types-ext:fiber-type;
         config false;
         description "fiber-type";
       }

       leaf span-length {
         type decimal64 {
           fraction-digits 2;
         }
         units "km";
         config false;
         description "the lenght of the fiber span in km";
       }

       leaf input-power {
         type decimal64 {
           fraction-digits 2;
         }
         units "dBm";
         config false;
         description
         "Average input power level estimated at the receiver
            of the link";
       }
```

```
       leaf output-power {
         type decimal64 {
           fraction-digits 2;
         }
         units "dBm";
         description
         "Mean launched power at the transmitter of the link";
       }

       leaf pmd {
         type decimal64 {
           fraction-digits 8;
           range "0..max";
         }
         units "ps/(km)^0.5";
         config false;
         description
         "Polarization Mode Dispersion";
       }

       leaf cd {
         type decimal64 {
           fraction-digits 5;
         }
         units "ps/nm/km";
         config false;
         description
         "Cromatic Dispersion";
       }

       leaf osnr {
         type l0-types-ext:snr;
         config false;
         description
         "Optical Signal-to-Noise Ratio (OSNR) estimated
            at the receiver";
       }

       leaf sigma {
         type decimal64 {
           fraction-digits 5;
         }
         units "dB";
         config false;
         description
         "sigma in the Gausian Noise Model";
       }
     }
```

```
     grouping optical-channel-data {
     description
       "optical impairment data per channel/wavelength";
     leaf bit-rate {
       type decimal64 {
         fraction-digits 8;
           range "0..max";
       }
       units "Gbit/s";
       config false;
       description
         "Gross bit rate";
     }

     leaf BER {
       type decimal64 {
         fraction-digits 18;
         range "0..max";
       }
       config false;
       description
         "BER (Bit Error Rate)";
     }

     leaf ch-input-power {
       type decimal64 {
         fraction-digits 2;
       }
       units "dBm";
       config false;
       description
         "Per channel average input power level
         estimated at the receiver of the link";
     }

     leaf ch-pmd {
       type decimal64 {
           fraction-digits 8;
         range "0..max";
       }
       units "ps/(km)^0.5";
       config false;
       description
         "per channel Polarization Mode Dispersion";
     }

     leaf ch-cd {
       type decimal64 {
```

```
               fraction-digits 5;
       }
       units "ps/nm/km";
       config false;
             description
         "per channel Cromatic Dispersion";
     }

     leaf ch-osnr {
       type l0-types-ext:snr;
       config false;
       description
         "per channel Optical Signal-to-Noise Ratio
               (OSNR) estimated at the receiver";
      }

       leaf q-factor {
       type decimal64 {
         fraction-digits 5;
       }
       units "dB";
       config false;
         description
         "q-factor estimated at the receiver";
       }
     }

     /*
      * Groupings
      */

     grouping amplifier-params {
       description "describes parameters for an amplifier";
       container amplifier {
         description
           "amplifier type, operatonal parameters are described.";
         leaf type-variety {
           type string ;
           mandatory true ;
           description
             "String identifier of amplifier type referencing
             a specification in a separate equipment catalog";
         }
         container operational {
           description "amplifier operational parameters";
           list amplifier-element {
             description
               "The list of parallel amplifier elements within an
```

```
              amplifier used to amplify different frequency ranges.";
            leaf name {
              type string;
              description
                "The name of the amplifier element as specified in
                the vendor's specification associated with the
                type-variety.";
            }
            container frequency-range {
              description
                "The frequency range amplified by the amplifier
                element.";
              uses l0-types-ext:frequency-range;
            }
            leaf actual-gain {
              type decimal64 {
                fraction-digits 2;
              }
              units dB ;
              mandatory true ;
              description "..";
            }
            leaf tilt-target {
              type decimal64 {
                fraction-digits 2;
              }
              mandatory true ;
              description "..";
            }
            leaf out-voa {
              type decimal64 {
                fraction-digits 2;
              }
              units dB;
              mandatory true;
              description "..";
            }
            leaf in-voa {
              type decimal64 {
                fraction-digits 2;
              }
              units dB;
              mandatory true;
              description "..";
            }
            uses power-param;
          }  // 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";
         leaf type-variety {
           type string ;
       mandatory true ;
           description "fiber type";
         }
         leaf length {
           type decimal64 {
             fraction-digits 2;
           }
           units km;
       mandatory true ;
       description "length of fiber";
         }
         leaf loss-coef {
           type decimal64 {
             fraction-digits 2;
           }
           units dB/km;
       mandatory true ;
       description "loss coefficient of the fiber";
         }
         leaf total-loss {
           type decimal64 {
             fraction-digits 2;
           }
           units dB;
       mandatory true ;
           description
             "includes all losses: fiber loss and conn-in and
              conn-out losses";
         }
         leaf pmd{
           type decimal64 {
             fraction-digits 2;
           }
           units sqrt(ps);
       description "pmd of the fiber";
         }
         leaf conn-in{
```

```
          type decimal64 {
            fraction-digits 2;
          }
          units dB;
      description "connector-in";
        }
        leaf conn-out{
          type decimal64 {
            fraction-digits 2;
          }
          units dB;
      description "connector-out";
        }
      }
    }

    grouping roadm-express-path {
      description
        "The optical impairments of a ROADM express path.";
      leaf roadm-pmd {
        type decimal64 {
          fraction-digits 8;
          range "0..max";
        }
        units "ps/(km)^0.5";
        description
          "Polarization Mode Dispersion";
      }
      leaf roadm-cd {
        type decimal64 {
          fraction-digits 5;
        }
        units "ps/nm";
        description "Chromatic Dispersion";
      }
      leaf roadm-pdl {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        description "Polarization dependent loss";
      }
      leaf roadm-inband-crosstalk {
        type decimal64 {
          fraction-digits 2;
        }
        units dB;
        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 1 blocked";
      }
      leaf roadm-maxloss {
        type decimal64 {
          fraction-digits 2;
        }
        units dB;
        description
          "This is the maximum expected add path loss from the
            ROADM ingress to the ROADM egress
            assuming no additional add path loss is added";
      }
    }

    grouping roadm-add-path {
      description "The optical impairments of a ROADM add path.";
      leaf roadm-pmd {
        type decimal64 {
          fraction-digits 8;
          range "0..max";
        }
        units "ps";
        description
          "Polarization Mode Dispersion";
      }
      leaf roadm-cd {
        type decimal64 {
          fraction-digits 5;
        }
        units "ps/nm";
        description "Cromatic Dispersion";
      }
      leaf roadm-pdl {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        description "Polarization dependent loss";
      }
      leaf roadm-inband-crosstalk {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        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 1 blocked.
            In the case of add path it is the total
            of the add block
            + egress WSS crosstalk contributions.";
      }
      leaf roadm-maxloss {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        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 should be based
            on worst case expected amplifier gain due to
            ripple or gain uncertainty";
      }
      leaf roadm-pmax {
        type decimal64 {
          fraction-digits 2;
        }
        units dBm ;
        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 may reflect either add amplifier power
            contraints 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-ext:snr;
        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, should be used
            (if both are defined).";
      }
      leaf roadm-noise-figure {
        type decimal64 {
          fraction-digits 5;
        }
        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.";
      }
    }

    grouping roadm-drop-path {
      description "roadm drop block path optical impairments";
      leaf roadm-pmd {
        type decimal64 {
          fraction-digits 8;
          range "0..max";
        }
        units "ps/(km)^0.5";
        description
          "Polarization Mode Dispersion";
      }
      leaf roadm-cd {
        type decimal64 {
          fraction-digits 5;
        }
        units "ps/nm";
        description "Chromatic Dispersion";
      }
      leaf roadm-pdl {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        description "Polarization dependent loss";
```

```
       }
       leaf roadm-inband-crosstalk {
         type decimal64 {
           fraction-digits 2;
         }
         units dB;
         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 1 blocked.
             In the case of drop path it is the total
             of the ingress
             to drop e.g. WSS and drop block crosstalk
             contributions.";
       }
       leaf roadm-maxloss {
         type decimal64 {
           fraction-digits 2;
         }
         units dB ;
         description
           "The net loss from the ROADM input,to the output
             of the drop block.
             If 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 contraints.
             The max value correspond to worst case expected loss,
             including amplifier gain ripple or uncertainty.
             It is the maximum output power of the drop
             amplifier.";
       }
       leaf roadm-minloss {
         type decimal64 {
           fraction-digits 2;
         }
         units dB ;
         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
             contraints.
             The min value correspond to best case expected loss,
```

```
            including amplifier gain ripple or uncertainty.";
      }
      leaf roadm-typloss {
        type decimal64 {
          fraction-digits 2;
        }
        units dB ;
        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 contraints.
            The typ value correspond to typical case
            expected loss.";
      }
      leaf roadm-pmin {
        type decimal64 {
          fraction-digits 2;
        }
        units dBm ;
        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 min per
            carrier power levels
            expected at the output of the drop block.
            A detail example of the comparison using
            these parameters is
            detailed in section xxx of the document yyy.";
      }
      leaf roadm-pmax {
        type decimal64 {
          fraction-digits 2;
        }
        units dBm ;
        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 best case per
             carrier power levels expected at the output of the
             drop block.
             A detail example of the comparison using
             these parameters
             is detailed in section xxx of the document yyy";
       }
       leaf roadm-ptyp {
         type decimal64 {
           fraction-digits 2;
         }
         units dBm ;
         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-ext:snr;
         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 should be used";
       }
       leaf roadm-noise-figure {
         type decimal64 {
           fraction-digits 5;
```

```
         }
         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";
       }
     }

     grouping concentratedloss-params{
       description "concentrated loss";
       container concentratedloss{
       description "concentrated loss";
         leaf loss {
           type decimal64 {
             fraction-digits 2;
           }
           units dB ;
           mandatory true;
           description "..";
         }
       }
     }

     grouping power-param{
       description
         "optical power or PSD after the ROADM or after the out-voa";
       choice power-param {
         description
           "select the mode: channel power or power spectral density";
         case channel-power {
           when "/nw:networks/nw:network/nt:link/tet:te
               /tet:te-link-attributes/OMS-attributes
               /equalization-mode='carrier-power'";
           leaf nominal-carrier-power{
             type decimal64 {
                 fraction-digits 2;
             }
```

```
          units dBm ;
          description
            " Reference channel power. Same grouping is used for the
            OMS power after the ROADM (input of the OMS) or after the
            out-voa of each amplifier. ";
        }
      }
      case power-spectral-density{
        when "/nw:networks/nw:network/nt:link/tet:te
            /tet:te-link-attributes/OMS-attributes
            /equalization-mode='power-spectral-density'";
        leaf nominal-power-spectral-density{
          type decimal64 {
              fraction-digits 16;
          }
          units W/Hz ;
          description
            " Reference power spectral density after
              the ROADM or after the out-voa.
              Typical value : 3.9 E-14, resolution 0.1nW/MHz";
        }
      }
    }
  }

  grouping oms-general-optical-params {
    description "OMS link optical parameters";
    leaf generalized-snr {
      type l0-types-ext:snr;
      description "generalized snr";
    }
    leaf equalization-mode{
      type identityref {
        base l0-types-ext:type-power-mode;
      }
      mandatory true;
      description "equalization mode";
    }
    uses power-param;
  }

  grouping otsi-group {
    description "OTSiG definition , representing client
     digital information stream supported by 1 or more OTSi";

    list otsi {
      key "otsi-carrier-id";
      config false;
```

```
         description
           "list of OTSi contained in 1 OTSiG.
           The list could also be of only 1 element";
         leaf otsi-carrier-id {
           type int16;
           description "OTSi carrier-id";
         }

   /*any OTSi as signal generated by transceiver and*/
   /* attached to a transponder.*/


         leaf transponder-ref {
           type leafref {
             path "../../../../../transponder/transponder-id";
           }
           description
             "Reference to the configured transponder";
         }
         leaf transceiver-ref {
           type leafref {
             path "deref(../transponder-ref)/../transceiver/" +
                  "transceiver-id";
           }
           description
             "Reference to the configured transceiver " ;
         }
         leaf configured-mode {
           type leafref {
             path "deref(../transceiver-ref)/../supported-modes/" +
                  "supported-mode/mode-id";
           }
           description
             "Reference to the configured mode for transceiver
              compatibility approach";
         }
         uses l0-types-ext:common-transceiver-configured-param;
       } // OTSi list
     } // OTSiG grouping

     grouping media-channel-groups {
       description "media channel groups";
       list media-channel-group {
       key "i";
         description
           "list of media channel groups";
         leaf i {
           type int16;
```

```
             description "index of media channel group member";
         }

         list media-channels {
           key "flexi-n";
           description
             "list of media channels represented as (n,m)";

     // this grouping add both n.m values
           uses l0-types:flexi-grid-frequency-slot;

           leaf otsi-group-ref {
             type leafref {
               path "/nw:networks/nw:network/nw:node/tet:te" +
                   "/tet:tunnel-termination-point" +
                   "/otsi-group/otsi-group-id" ;
               }
             description
               "Reference to the otsi-group list to get otsi-group
               identifier of the
               OTSiG carried by this media channel
               that reports the transient stat";
           }
           leaf otsi-ref {
             type leafref {
               path "/nw:networks/nw:network/nw:node/tet:te" +
                   "/tet:tunnel-termination-point/"
                  +"otsi-group[otsi-group-id=current()"
                  +"/../otsi-group-ref]/"
                  + "otsi/otsi-carrier-id" ;
             }
             description
                "Reference to the otsi list supporting
                the related OTSiG to get otsi identifier";
           }
           leaf delta-power{
             type decimal64 {
                 fraction-digits 2;
             }
             units dB ;
             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 "OMS description";
       list OMS-elements {
           key "elt-index";
           description
             "defines the spans and the amplifier blocks of
             the amplified lines";
           leaf elt-index {
             type uint16;
             description
               "ordered list of Index of OMS element
               (whether it's a Fiber, an EDFA or a
   Concentratedloss)";
           }
           leaf oms-element-uid {
             type string;
             description
               "unique id of the element if it exists";
           }

             choice element {
               mandatory true;
               description "OMS element type";
               case amplifier {
                 uses amplifier-params ;
               }
               case fiber {
                 uses fiber-params ;
               }
               case concentratedloss {
                 uses concentratedloss-params ;
               }
             }

       }
     }

   /* 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";
      }
```

```
     }

     augment "/nw:networks/nw:network/nw:node" {
       when "../nw:network-types/tet:te-topology" +
            "/optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for Optical Impairment.";
       }
       description
         "Node augmentation for optical impairments data.";
       list transponder {
         key "transponder-id";
         config false;
         description "list of transponder";
         leaf transponder-id {
           type uint32;
           description "transponder identifier";
         }

         list transceiver {
           key "transceiver-id";
           config false;
           description "list of transceiver related to a transponder";
           leaf transceiver-id {
             type uint32;
             description "transceiver identifier";
           }
           leaf termination-type-capabilities {
             type enumeration {
               enum tunnel-only {
                 description
                   "The transceiver can only be used in an Optical
                   Tunnel termination configuration.";
               }
               enum 3r-only {
                 description
                   "The transceiver can only be used in a 3R
                   configuration.";
               }
               enum 3r-or-tunnel {
                 description
                   "The transceiver can be configure to be used either
                   in an Optical Tunnel termination configuration or in
                   a 3R configuration.";
               }
             }
             description
               "Describes whether the tranceiver 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 tranceiver supports 3R
                configuration.";
            }
            type enumeration {
              enum unidir {
                description
                  "Unidirectional 3R configuration.";
              }
              enum bidir {
                description
                  "Bidirectional 3R configuration.";
              }
            }
            description
              "Describes the supported 3R configuration type.";
          }
          leaf configured-termination-type {
            type enumeration {
              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
              tranceiver is used in an Optical Tunnel termination
              configuration or in a 3R configuration.

              If empty, it means that the transcevier is not used.";
          }
          uses l0-types-ext:transceiver-capabilities;
        } // end of list of transceiver
      } // end list of transponder
    }
```

```
     augment "/nw:networks/nw:network/nt:link/tet:te"
           + "/tet:te-link-attributes"   {
       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for Optical Impairment.";
       }
       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:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for Impairment with
            non-sliceable transponder model";
       }
       description
         "Tunnel termination point augmentation for non-sliceable
          transponder model.";

       list otsi-group {
         key "otsi-group-id";
         config false;
         description
           "the list of possible OTSiG representing client digital
           stream";
         leaf otsi-group-id {
           type int16;
           description "index of otsi-group element";
         }
         uses otsi-group;
       } // list of OTSiG
       list transceiver {
         config false;
         description
           "The list of the tranceivers used by the TTP.";
         leaf transponder-ref {
```

```
          type leafref {
            path "../../../../transponder/transponder-id";
          }
          description
            "The reference to the transponder hosting the tranceiver
            of the TTP.";
        }
        leaf tranceiver-ref {
          type leafref {
            path "deref(../transponder-ref)/../transceiver" +
                 "/transceiver-id";
          }
          description
            "The reference to the tranceiver of the TTP.";
        }
      } // list of tranceivers
    } // end of augment

    augment "/nw:networks/nw:network/nw:node/tet:te"
     + "/tet:tunnel-termination-point" {
     when "/nw:networks/nw:network/nw:network-types"
      +"/tet:te-topology/"
      + "optical-imp-topo:optical-impairment-topology" {
      description
        "This augment is only valid for optical impairment
         with sliceable transponder model";
     }
     description
       "Tunnel termination point augmentation for sliceable
        transponder model.";
     uses sliceable-transponder-attributes;
    }

    augment "/nw:networks/nw:network/nw:node/tet:te"
          + "/tet:te-node-attributes" {
      when "/nw:networks/nw:network/nw:network-types"
         + "/tet:te-topology"
         + "/optical-imp-topo:optical-impairment-topology" {

        description
          "This augment is only valid for Optical Impairment
          topology";
      }
      description
        "node attributes augmentantion for optical-impairment ROADM
         node";

      list roadm-path-impairments {
```

```
        key "roadm-path-impairments-id";
        config false;
        description
          "The set of optical impairments related to a ROADM path.";

        leaf roadm-path-impairments-id {
          type uint32;
          description "index of the ROADM path-impairment list";
        }
        choice impairment-type {
          description "type path impairment";
          case roadm-express-path {
            list roadm-express-path {
              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.";
              container frequency-range {
                description
                  "The frequency range for which these optical
                  impairments apply.";
                uses l0-types-ext:frequency-range;
              }
              uses roadm-express-path;
            }
          }
          case roadm-add-path {
            list roadm-add-path {
              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.";
              container frequency-range {
                description
                  "The frequency range for which these optical
                  impairments apply.";
                uses l0-types-ext:frequency-range;
              }
              uses roadm-add-path;
            }
          }
          case roadm-drop-path {
            list roadm-drop-path {
              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.";
              container frequency-range {
                description
                  "The frequency range for which these optical
                  impairments apply.";
                uses l0-types-ext:frequency-range;
              }
              uses roadm-drop-path;
            }
          }
        }
      } // list path impairments
    } // augmentation for optical-impairment ROADM

    augment "/nw:networks/nw:network/nw:node/tet:te/"
          + "tet:information-source-entry/tet:connectivity-matrices"{
      when "/nw:networks/nw:network/nw:network-types"
         + "/tet:te-topology/"
         + "optical-imp-topo: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 {
        type leafref {
          path "../../../tet:te-node-attributes/"
          + "roadm-path-impairments/roadm-path-impairments-id";
        }
        description "pointer to the list set of ROADM optical
        impairments";
      }
    } // 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:networks/nw:network/nw:network-types"
         + "/tet:te-topology/"
         + "optical-imp-topo: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 {
         type leafref {
           path "../../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id";
         }
         description "pointer to the list set of ROADM optical
         impairments";
       }
     } // augmentation connectivity-matrix information-source

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:te-node-attributes/tet:connectivity-matrices" {
       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for Optical Impairment
           topology ";
       }

       description
         "Augment default TE node connectivity matrix.";
       leaf roadm-path-impairments {
         type leafref {
           path "../../roadm-path-impairments/"
           + "roadm-path-impairments-id";
         }
         config false; /*the identifier in the list */
          /*"roadm-path-impairments" of ROADM optical impairment*/
                       /*is read-only as the rest of attributes*/
         description "pointer to the list set of ROADM optical
         impairments";
       }
     } // augmentation connectivity-matrices

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:te-node-attributes/"
           + "tet:connectivity-matrices/tet:connectivity-matrix" {
       when "/nw:networks/nw:network/nw:network-types"
```

```
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
           "This augment is only valid for
           Optical Impairment topology ";
       }

       description
         "Augment TE node connectivity matrix entry.";

       leaf roadm-path-impairments {
         type leafref {
           path "../../../roadm-path-impairments/"
           + "roadm-path-impairments-id";
         }
         config false;
         description "pointer to the list set of ROADM optical
          impairments";
       }
     } // augmentation connectivity-matrix

     augment "/nw:networks/nw:network/nw:node/tet:te/"
           + "tet:tunnel-termination-point/"
           + "tet:local-link-connectivities" {

       when "/nw:networks/nw:network/nw:network-types"
          + "/tet:te-topology/"
          + "optical-imp-topo:optical-impairment-topology" {
         description
         "This augment is only valid for Optical Impairment topology ";
       }

       description
         "Augment default TTP LLC.";
       leaf add-path-impairments {
         type leafref {
           path "../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id" ;
         }
         config false;
         description "pointer to the list set of ROADM optical
          impairments";
       }
       leaf drop-path-impairments {
         type leafref {
           path "../../../tet:te-node-attributes/"
           + "roadm-path-impairments/roadm-path-impairments-id" ;
         }
```

```
          config false;
          description "pointer to the list set of ROADM
          optical impairments";
        }
      } // 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:networks/nw:network/nw:network-types"
           + "/tet:te-topology/"
           + "optical-imp-topo:optical-impairment-topology" {
          description
            "This augment is only valid for
             Optical Impairment topology ";
        }

        description
          "Augment TTP LLC entry.";
        leaf add-path-impairments {
          type leafref {
            path "../../../../tet:te-node-attributes/"
            + "roadm-path-impairments/roadm-path-impairments-id" ;
          }
          config false;
          description "pointer to the list set of ROADM optical
           impairments";
        }
        leaf drop-path-impairments {
          type leafref {
            path "../../../../tet:te-node-attributes/"
            + "roadm-path-impairments/roadm-path-impairments-id" ;
          }
          config false;
          description "pointer to the list set of ROADM optical
          impairments";
        }
      } // augmentation local-link-connectivity
    }
    <CODE ENDS>
```

5. Security Considerations

The configuration, state, and action data defined in this document are designed to be accessed via a management protocol with a secure transport layer, such as NETCONF [RFC6241]. The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF users to a preconfigured subset of all available NETCONF protocol operations and content.

A number of configuration data nodes defined in this document are read-only; however, these data nodes may be considered sensitive or vulnerable in some network environments (TBD).

6. 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 modules in the YANG Module Names registry [RFC7950]:

```
--------------------------------------------------------------------
name:      ietf-optical-impairment-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-optical-impairment-
topology
prefix:    optical-imp-topo
reference: RFC XXXX (TDB)
--------------------------------------------------------------------
```

7. Acknowledgments

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

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