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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.

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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.

This document augments the generic TE topology draft [I-D.ietf-teas-yang-te-topo] 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:

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

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

- configuration data
- 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]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[I-D.ietf-teas-yang-te-topo]

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

A Transponder is the element that sends and receives the optical signal from a fiber. A transponder is typically characterized by its data rate and the maximum distance the signal can travel. Channel frequency, per channel input power, FEC and Modulation are also associated with a transponder. From a path computation point of view, the selection of the compatible source and destination transponders is an important factor for optical signal to traverse through the fiber. There are three main approaches to determine optical signal compatibility. Application Code based on G.698.2 is one approach that only checks the code at both ends of the link. Another approach is organization codes that are specific to an organization or a vendor. The third approach is specify all the relevant parameters explicitly, e.g., FEC type, Modulation type, etc.

[Editor's note: The current YANG model described in Section 3 with respect to the relationship between the transponder attributes and the OTSi will need to be investigated in the future revision]

2.6. 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.

2.7. 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.

2.8. 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.]

2.8.1. Integrated ROADM Architecture with Integrated Optical Transponders

Figure 2 and Figure 6 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 6: ROADM Architectiure with Integrated Transponders

2.8.2. **Integrated ROADMs with Integrated Optical Transponders and Single Channel Add/Drop Interfaces for Remote Optical** Transponders

Figure 7 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 7: ROADM Architectiure with Remote Transponders

2.8.3. 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 8 below.

As this document defines TE topology YANG model augmentations [I-D.ietf-teas-yang-te-topo] 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 8: Disaggregated ROADM Architecture with Remote Transponders

2.8.4. 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)

- o Optical amplifier noise due to amplified spontaneous emission (ASE)
- o In-band cross-talk
- o 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:

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

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

- o 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 [I-D.ietf-teas-yang-te-topo]. 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).

[I-D.ietf-teas-yang-te-topo] 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)

```
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/nt:link/tet:te/
  tet:te-link-attributes:
    +--ro OMS-attributes
       +--ro generalized-snr?                        decimal64
       +--ro equalization-mode                       identityref
       +--ro (power-param)?
       |  +--:(channel-power)
       |  |  +--ro nominal-channel-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      uint16
       |     +--ro flexi-m?     uint16
       |     +--ro OTSiG-ref?   -> /nw:networks/network/node/tet:te/
             tunnel-termination-point/OTSiG-element/OTSiG-identifier
       |     +--ro OTSi-ref?    -> /nw:networks/network/node/tet:te/
             tunnel-termination-point/
             OTSiG-element[OTSiG-identifier=current()/../OTSiG-ref]/
             OTSiG-container/OTSi/OTSi-carrier-id
       +--ro OMS-elements* [elt-index]
          +--ro elt-index    uint16
          +--ro uid?         string
          +--ro type         identityref
          +--ro element
             +--ro (element)?
                +--:(amplifier)
                |  +--ro amplifier
                |     +--ro type-variety    string
                |     +--ro operational
                |        +--ro actual-gain                 decimal64
                |        +--ro tilt-target                 decimal64
                |        +--ro out-voa                     decimal64
```

```
                   |        +--ro in-voa                      decimal64
                   |        +--ro (power-param)?
                   |           +--:(channel-power)
                   |           |  +--ro nominal-channel-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 OTSiG-element* [OTSiG-identifier]
      |  +--ro OTSiG-identifier    int16
      |  +--ro OTSiG-container
      |     +--ro OTSi* [OTSi-carrier-id]
      |        +--ro OTSi-carrier-id           int16
      |        +--ro OTSi-carrier-frequency?   decimal64
      |        +--ro OTSi-signal-width?        decimal64
      |        +--ro channel-delta-power?      decimal64
      +--ro transponders-list* [transponder-id]
         +--ro transponder-id                      uint32
         +--ro (mode)?
         |  +--:(G.692.2)
         |  |  +--ro standard-mode?                standard-mode
         |  +--:(organizational-mode)
         |  |  +--ro operational-mode?             operational-mode
         |  |  +--ro organization-identifier?      vendor-identifier
         |  +--:(explicit-mode)
         |     +--ro available-modulation-types*   identityref
         |     +--ro configured-modulation-type?   identityref
         |     +--ro available-baud-rates*         uint32
         |     +--ro configured-baud-rate?         uint32
         |     +--ro available-FEC-types*          identityref
         |     +--ro configured-FEC-type?          identityref
         |     +--ro FEC-code-rate?                decimal64
         |     +--ro FEC-threshold?                decimal64
         +--ro power?                              int32
```

```
          +--ro power-min?                          int32
          +--ro power-max?                          int32
     augment /nw:networks/nw:network/nw:node/tet:te/
     tet:tunnel-termination-point:
       +--ro 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 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 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?               decimal64
             |     +--ro roadm-noise-figure?       decimal64
             +--:(roadm-drop-path)
                +--ro roadm-drop-path
                   +--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?               decimal64
                   +--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?   -> ../../../
       tet:te-node-attributes/roadm-path-impairments/
       roadm-path-impairments-id
     augment /nw:networks/nw:network/nw:node/tet:te/
```

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

4. Optical Impairment Topology YANG Model

[Editor's note: YANG code below may have to be updated before submission!]

```
   <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 "layer0-types";
     }

     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>
        Editor:   Victor Lopez <victor.lopezalvarez@telefonica.com>
        Editor:   Gabriele Galimberti <ggalimbe@cisco.com>
        Editor:   Giovanni Martinelli <giomarti@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.

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        authors of the code.  All rights reserved.

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

     revision 2020-03-09 {
```

```
       description
         "Initial Version";
       reference
         "RFC XXXX: A Yang Data Model for Impairment-aware
          Optical Networks";
     }

     // identity

     identity modulation {
       description "base identity for modulation type";
     }

     identity QPSK {
       base modulation;
       description
         "QPSK (Quadrature Phase Shift Keying) modulation";
     }

     identity DP-QPSK {
       base modulation;
       description
         "DP-QPSK (Dual Polarization Quadrature
          Phase Shift Keying) modulation";
     }
     identity QAM8 {
       base modulation;
       description
         "8QAM (8-State Quadrature Amplitude Modulation) modulation";
     }
     identity QAM16 {
       base modulation;
       description
         "QAM16 (Quadrature Amplitude Modulation)";
     }
     identity DP-QAM8 {
       base modulation;
       description
         "DP-QAM8 (Dual Polarization Quadrature Amplitude Modulation)";
     }
     identity DC-DP-QAM8 {
       base modulation;
       description
       "DC DP-QAM8 (Dual Polarization Quadrature Amplitude Modulation)";
     }
     identity DP-QAM16 {
       base modulation;
       description
```

```
         "DP-QAM16 (Dual Polarization Quadrature Amplitude Modulation)";
     }
     identity DC-DP-QAM16 {
       base modulation;
       description
       "DC DP-QAM16 (Dual Polarization Quadrature
       Amplitude Modulation)";
     }

     identity FEC {
       description
         "Enumeration that defines the type of
          Forward Error Correction";
     }
     identity reed-solomon {
       base FEC;
         description
     "Reed-Solomon error correction";
     }
     identity hamming-code {
       base FEC;
         description
     "Hamming Code error correction";
     }
     identity golay {
       base FEC;
         description "Golay error correction";
     }

     // typedef

     typedef fiber-type {
       type enumeration {
         enum G.652 {
         description "G.652 Standard Singlemode Fiber";
         }
         enum G.654 {
           description "G.654 Cutoff Shifted Fiber";
         }
         enum G.653 {
           description "G.653 Dispersion Shifted Fiber";
         }
         enum G.655 {
           description "G.655 Non-Zero Dispersion Shifted Fiber";
         }
         enum G.656 {
           description "G.656 Non-Zero Dispersion for Wideband
                  Optical Transport";
```

```
         }
         enum G.657 {
           description "G.657 Bend-Insensitive Fiber";
         }
       }
       description
         "ITU-T based fiber-types";
     }

   /*temporary defined here for disalignment with*/
   /* ietf-layer0-types module*/

     typedef operational-mode {
       type string;
       description
         "Vendor-specific mode that guarantees
         interoperability.";
       reference "ITU-T G.698.2 (11/2018)";
     }

   // temporary defined here for disalignment with
   //ietf-layer0-types module
     typedef standard-mode {
       type string;
       description
         "ITU-T G.698.2 standard mode that guarantees
          interoperability.
          It must be an string with the following format:
          B-DScW-ytz(v) where all these attributes
          are conformant
          to the ITU-T recomendation";
       reference "ITU-T G.698.2 (11/2018)";
     }

   // temporary defined here for disalignment
   //with ietf-layer0-types module
     typedef vendor-identifier {
       type string;
       description
         "vendor identifier that uses vendor-specific mode";
       reference
         "RFC7581: Routing and Wavelength Assignment Information
          Encoding for Wavelength Switched Optical Networks";
     }

     // grouping

     grouping transponder-attributes {
```

```
       description "Configuration of an optical transponder";

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

       leaf configured-modulation-type {
         type identityref {
         base 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 FEC;
         }
```

```
         config false;
         description "List determining all the available FEC";
       }

       leaf configured-FEC-type {
         type identityref {
         base FEC;
         }
         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 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 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 decimal64 {
            fraction-digits 5;
          }
          units "dB";
          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 decimal64 {
         fraction-digits 5;
       }
         units "dB";
       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";
       }
     }

     grouping standard-mode {
       description
         "ITU-T G.698.2 standard mode that guarantees interoperability.
          It must be an string with the following format:
          B-DScW-ytz(v) where all these attributes are conformant
          to the ITU-T recomendation";

       leaf standard-mode {
         type standard-mode;
         config false;
         description
           "G.698.2 standard mode";
       }
     }

     grouping organizational-mode {
       description
         "Transponder operational mode supported by organizations or
          vendor";

       leaf operational-mode {
         type operational-mode;
         config false;
         description
           "configured organization- or vendor-specific
            application identifiers (AI) supported by the transponder";
       }

       leaf organization-identifier {
         type vendor-identifier;
         config false;
         description
```

```
         "organization identifier that uses organizational
            mode";

       }
     }

       /*
      * Identities
      */
     identity type-element {
       description
         "Base identity for element type";
     }

     identity Fiber {
       base type-element;
       description
         "Fiber element";
     }

     identity Roadm {
       base type-element;
       description
         "Roadm element";
     }

     identity Edfa {
       base type-element;
       description
         "Edfa element";
     }

     identity Concentratedloss {
       base type-element;
       description
         "Concentratedloss element";
     }

     identity type-power-mode {
       description
         "power equalization mode used within the
          OMS and its elements";
     }

     identity power-spectral-density {
       base type-power-mode;
       description
         "all elements must use power spectral density (W/Hz)";
```

```
     }

     identity channel-power {
       base type-power-mode;
       description
         "all elements must use power (dBm)";
     }

     /*
      * 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 operationnal parameters";
           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;
         }
       }
     }

     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 "roadm express path optical impairments";

       container roadm-express-path {
         description "roadm parameters per 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 "roadm add block path optical impairments";

      container roadm-add-path {
        description "roadm optical impairment parameters
        per 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 decimal64 {
            fraction-digits 5;
          }
          units "dB";
          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";

       container roadm-drop-path {
         description "roadm optical impairment parameters
         per drop 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.
              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 decimal64 {
             fraction-digits 5;
           }
           units "dB";
           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 ;
           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 "equalization-mode='channel-power'"; */
           leaf nominal-channel-power{
             type decimal64 {
                 fraction-digits 1;
             }
             units dBm ;
             description
               " Reference channel power after the ROADM or after
               the out-voa. ";
           }
         }
         case power-spectral-density{
    /*       when "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 decimal64 {
          fraction-digits 5;
        }
        units "dB@0.1nm";
        description "generalized snr";
      }
      leaf equalization-mode{
        type identityref {
          base type-power-mode;
        }
        mandatory true;
        description "equalization mode";
      }
      uses power-param;
    }

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

      container OTSiG-container {
        config false;
        description
          "the container contains the related list of OTSi.
          The list could also be of only 1 element";
       list OTSi {
         key "OTSi-carrier-id";
         description
           "list of OTSi's under OTSi-G";
         leaf OTSi-carrier-id {
           type int16;
           description "OTSi carrier-id";
           }
         leaf OTSi-carrier-frequency {
           type decimal64 {
             fraction-digits 3;
           }
           units GHz;
           config false;
           description
             "OTSi carrier frequency";
```

```
          }
          leaf OTSi-signal-width {
            type decimal64 {
              fraction-digits 3;
            }
            units GHz;
            config false;
            description
              "OTSi signal width";
          }
          leaf channel-delta-power {
            type decimal64 {
              fraction-digits 2;
            }
            units dB;
            config false;
            description
              "optional ; delta power to ref channel
               input-power applied
              to this media channel";
          }

        }
      }  // OTSiG container
    } // 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)";
          uses layer0-types:flexi-grid-channel;
          leaf OTSiG-ref {
            type leafref {
              path "/nw:networks/nw:network/nw:node/tet:te" +
                   "/tet:tunnel-termination-point" +
                   "/OTSiG-element/OTSiG-identifier" ;
```

```
             }
             description
                "Reference to the OTSiG list to get OTSiG
                 identifier of the
                 OSiG 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/"
                  +"OTSiG-element[OTSiG-identifier=current()"
                  +"/../OTSiG-ref]/"
                  + "OTSiG-container/OTSi/OTSi-carrier-id" ;
             }
             description
                "Reference to the OTSi list supporting the
                 related OTSiG" ;
           }

         } // 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 uid {
             type string;
             description
               "unique id of the element if it exists";
           }
           leaf type {
             type identityref {
                base type-element;
             }
         mandatory true;
```

```
         description "element type";
           }

           container element {
             description "element of the list of elements of the OMS";
             choice element {
           description "OMS element type";
               case amplifier {
    /*             when "type = 'Edfa'"; */
                 uses amplifier-params ;
               }
               case fiber {
   /*              when "type = 'Fiber'"; */
                 uses fiber-params ;
               }
               case concentratedloss {
   /*             when "type = '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/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 OTSiG-element {
            key "OTSiG-identifier";
            config false;
            description
            "the list of possible OTSiG representing client digital
             stream";

            leaf OTSiG-identifier {
               type int16;
                description "index of OTSiG element";
            }
            uses OTSiG;
        }

        list transponders-list {
            key "transponder-id";
        config false;
            description "list of transponders";
            leaf transponder-id {
          type uint32;
          description "transponder identifier";
            }

            choice mode {
                description "standard mode, organizational mode or
                 explicit mode";

                case G.692.2 {
                  uses standard-mode;
```

```
                }

                case organizational-mode {
                  uses organizational-mode;
                }

                case explicit-mode {
                  uses transponder-attributes;
                }
            }

            leaf power {
              type int32;
              units "dBm";
              config false;
              description "per channel power";
            }

            leaf power-min {
              type int32;
              units "dBm";
              config false;
              description "minimum power of the transponder";
            }
            leaf power-max {
              type int32;
              units "dBm";
              config false;
              description "maximum power of the transponder";
            }
      }
     }

     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 "list of set of optical impairments related
         to ROADM ";

         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 {
             uses roadm-express-path;
           }
           case roadm-add-path {
             uses roadm-add-path;
           }
           case roadm-drop-path {
             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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