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Y. Lee
SKKU (Sung Kyun Kwan University)
JL. Auge
Orange
V. Lopez
Telefonica
G. Galimberti
Cisco
D. Beller
Nokia
November 2, 2020

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 Assignment (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 Assignment (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:

- 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]
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

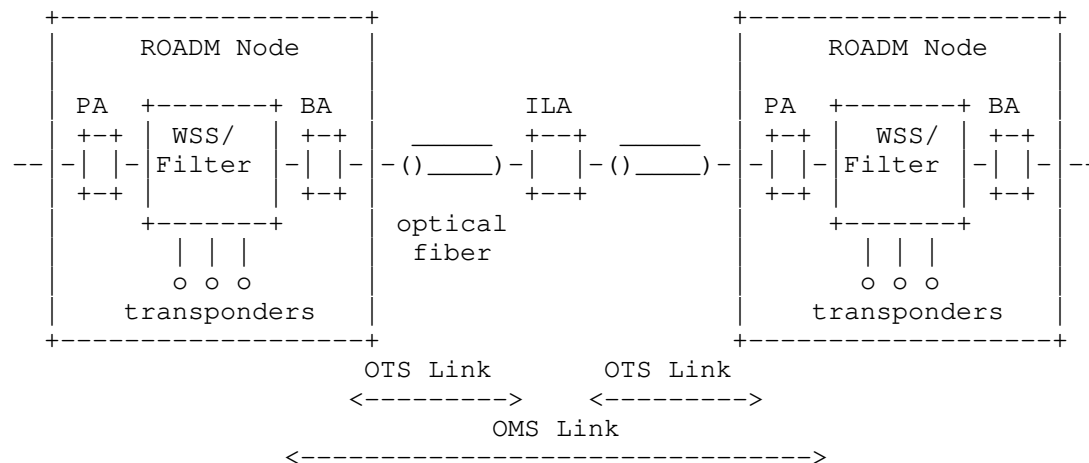
2.1. Control Plane Architecture

Figure 1 shows the control plane architecture.



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.



PA: Pre-Amplifier
 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 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.

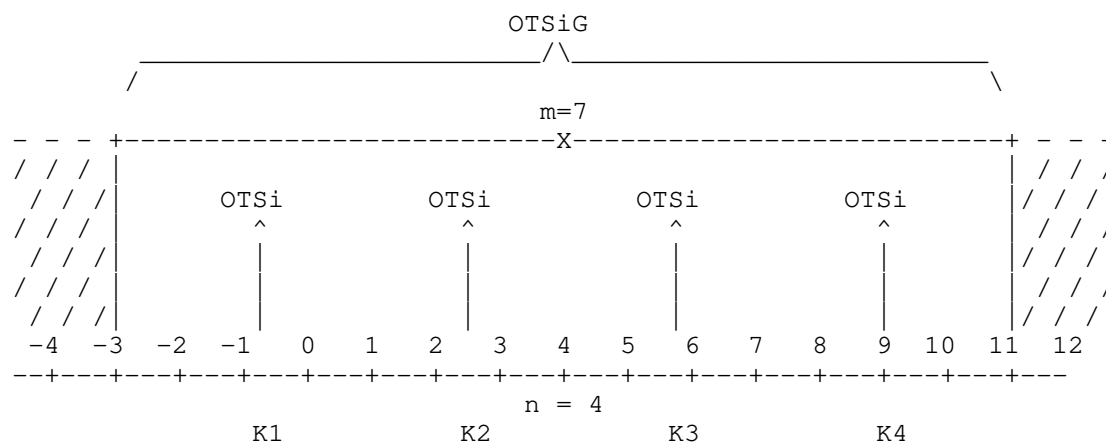


Figure 3: MC Example containing all 4 OTSi signals of an OTSiG

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.

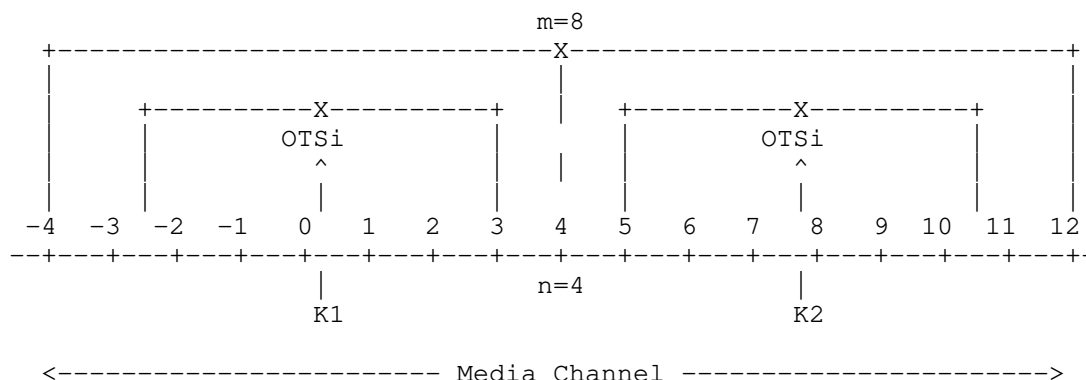


Figure 4: Figure Caption TBA

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 ROADMs 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 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.

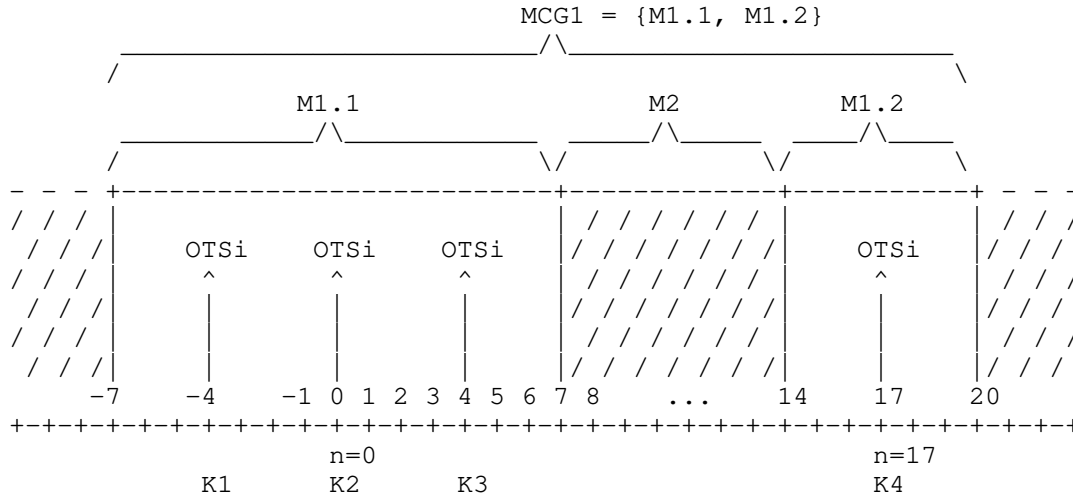


Figure 5: Figure Caption TBA

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, $\text{Power_in (@ ROADM Booster)} = \text{Power_out (@ ROADM Pre-Amplifier)} - \text{Power_loss (@ ROADM WSS/Filter)}$.

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:

- o Application Codes as defined in ITU-T Recommendation G.698.2 [G.698.2]
- o Organizational Modes
- o Explicit Modes

2.5.1. Application Codes

An application code represents 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.

2.5.2. Organizational Modes

Organizations like operator groups, industry fora, or equipment vendors can define organizational modes, which will allow these organizations to make use of advanced transceiver capabilities going beyond existing standardized application codes. Such 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. Two transceivers are inter-operable, 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 including:

- o FEC type
- o Modulation scheme
- o Encoding (mapping of bit patterns to symbols in the constellation diagram)
- o Baud rate (symbol rate)
- o 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.

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:

- o Supported transmitter tuning range with min/max nominal carrier frequency [f_tx_min, f_tx_max]
- o Supported transmitter tunability grid, the distance between two adjacent carrier frequencies (in GHz)
- o Supported transmitter power range [p_tx-min, p_tx_max]
- o Supported receiver channel power range [p_rx-min, p_rx_max]
- o 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. 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 ROADMs. So this document does not model the inside of ROADMs.

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.

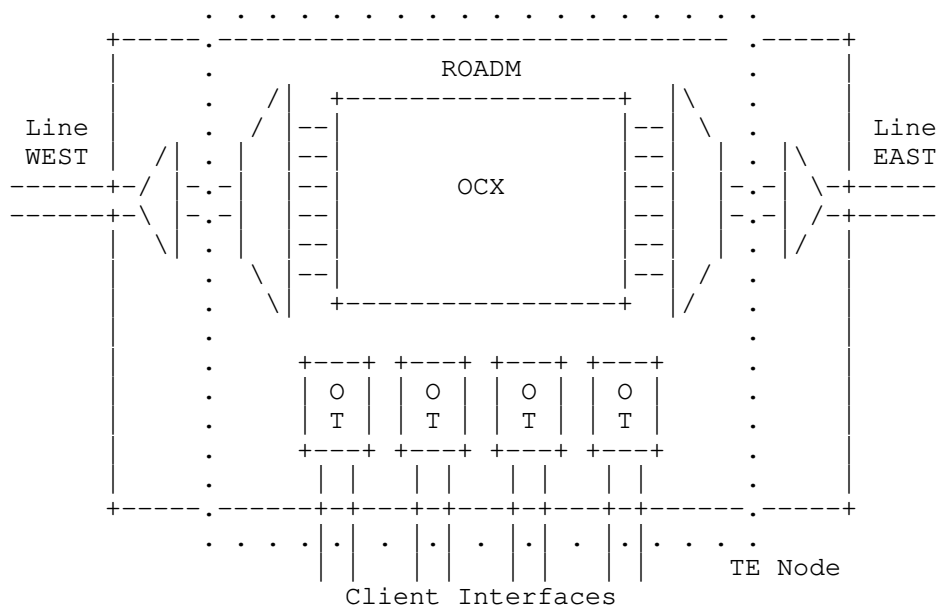


Figure 6: ROADM Architectiure with Integrated Transponders

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].

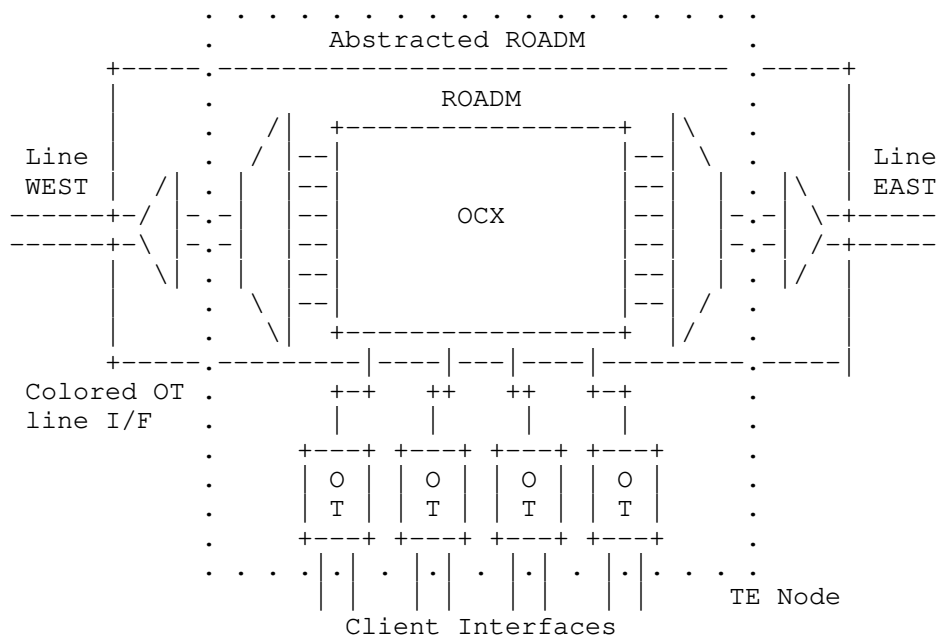


Figure 7: ROADM Architectiure with Remote Transponders

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.

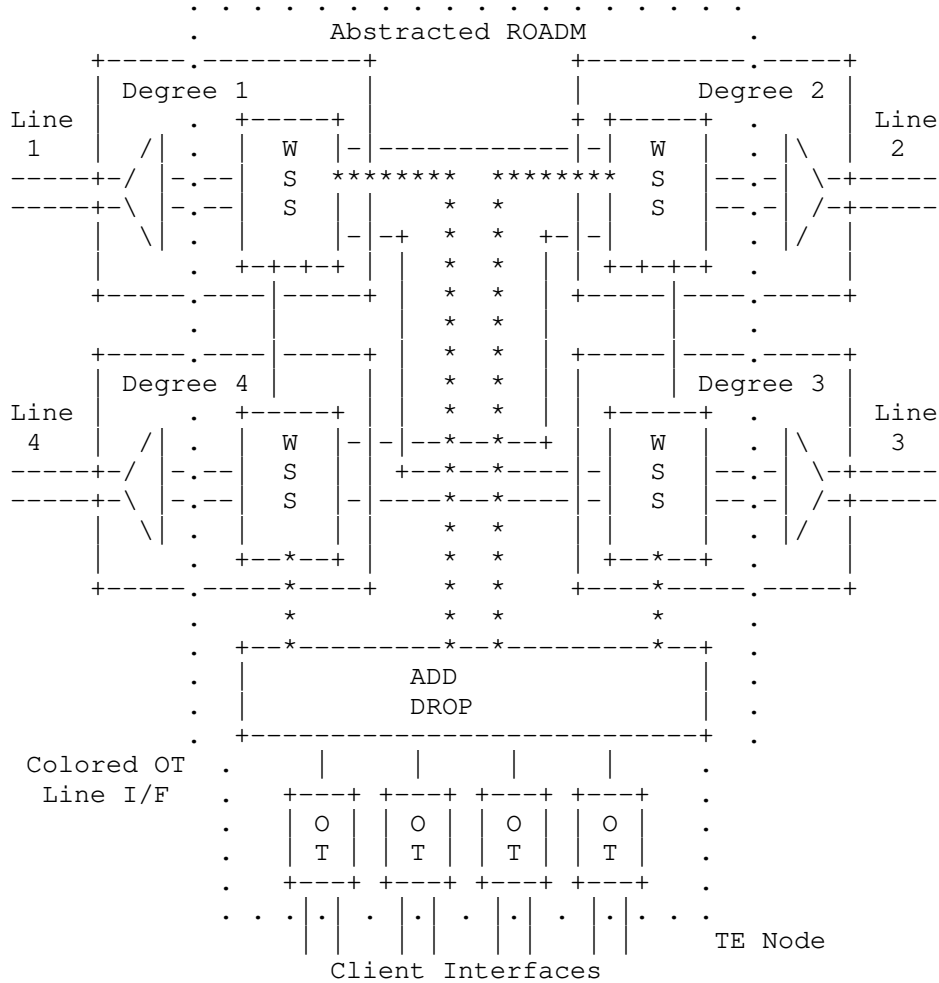


Figure 8: Disaggregated ROADM Architecture with Remote Transponders

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?                10-types-ext:snr
      +--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                  10-types:flexi-n
        | | +--ro flexi-m?                 10-types:flexi-m
        | | +--ro OTSiG-ref?               leafref
        | | +--ro OTSi-ref?                leafref
      +--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 otsi-group* [otsi-group-id]
    |   +--ro otsi-group-id      int16
    |   +--ro otsi* [otsi-carrier-id]
    |   |   +--ro otsi-carrier-id      int16
    |   |   +--ro transponder-ref?     leafref
    |   |   +--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 transponder* [transponder-id]
    |   +--ro transponder-id      uint32
    +--ro transceiver* [transceiver-id]
    |   +--ro transceiver-id      uint32
    |   +--ro supported-modes
    |   |   +--ro supported-mode* [mode-id]
    |   |   |   +--ro mode-id          string
    |   |   +--ro (mode)
    |   |   |   +--:(G.698.2)
    |   |   |   |   +--ro 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?
|   decimal64
+--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 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/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 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?        10-types-ext:snr
    |   |   +---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-typlloss?           decimal64
        +--ro roadm-pmin?               decimal64
        +--ro roadm-pmax?               decimal64
        +--ro roadm-ptyp?               decimal64
        +--ro roadm-osnr?                10-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 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 "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>
   Editor:   Victor Lopez <victor.lopezalvarez@telefonica.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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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 2020-10-13 {
  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";
}

// 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 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 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 10-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 Gaussian 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 Chromatic Dispersion";
    }

    leaf ch-osnr {
      type 10-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";
    }
  }

  /*
  * 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, operational 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
       constraints or WSS adjustment limits.
       Higher power transponders would need to have
```



```
        their launch power reduced
        to this value or lower";
    }
    leaf roadm-osnr {
        type 10-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";

    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 constraints.
    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
    constraints.
    The min value correspond to best case expected loss,
    including amplifier gain ripple or uncertainty.";
}
leaf roadm-typlloss {
  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 constraints.
    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 10-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 ;
            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 10-types-ext:snr;
    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";

      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 "/nw:networks/nw:network/nw:node/tet:te" +
            "/tet:tunnel-termination-point" +
            "/transponder/transponder-id";
        }
        description
          "Reference to the configured transponder";
      }
      leaf transceiver-ref {
        type leafref {
          path "/nw:networks/nw:network/nw:node/tet:te" +
            "/tet:tunnel-termination-point/"
            +"transponder[transponder-id=current()]"
            +"../transponder-ref]/"
            + "transceiver/transceiver-id" ;
        }
        description
          "Reference to the configured transceiver " ;
      }
      leaf configured-mode {
        type leafref {
          path "/nw:networks/nw:network/nw:node/tet:te" +
            "/tet:tunnel-termination-point/"
            +"transponder[transponder-id=current()]"
            +"../transponder-ref]/"+
            "transceiver[transceiver-id=current()]/"+
```

```
        "../transceiver-ref]/supported-modes/" +
        "supported-mode/mode-id";
    }
    description
        "Reference to the configured mode for transceiver
        compatibility approach";
    }
    uses 10-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 10-types:flexi-grid-frequency-slot;

            leaf OTSiG-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()]"
                }
            }
        }
    }
}
```



```

        + "../OTSiG-ref]"
        + "otsi/otsi-carrier-id" ;
    }
    description
        "Reference to the otsi list supporting
        the related OTSiG to get otsi identifier";
}

} // 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 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 OTSiG;
  } // list of OTSiG

  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";
      }
      uses 10-types-ext:transceiver-capabilities;
    } // end of list of transceiver

  } // end list of transponder

} // 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 "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.

8. References

8.1. Normative References

- [RFC7950] Bjorklund, M., Ed., "The YANG 1.1 Data Modeling Language", RFC 7950, DOI 10.17487/RFC7950, August 2016, <<https://www.rfc-editor.org/info/rfc7950>>.
- [RFC8040] Bierman, A., Bjorklund, M., and K. Watsen, "RESTCONF Protocol", RFC 8040, DOI 10.17487/RFC8040, January 2017, <<https://www.rfc-editor.org/info/rfc8040>>.
- [RFC8341] Bierman, A. and M. Bjorklund, "Network Configuration Access Control Model", STD 91, RFC 8341, DOI 10.17487/RFC8341, March 2018, <<https://www.rfc-editor.org/info/rfc8341>>.

8.2. Informative References

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Appendix A. Contributors

Aihua Guo
Huawei Technologies
Email: aguo@futurewei.com

Jonas Martensson
RISE
Email: jonas.martensson@ri.se

Appendix B. Additional Authors

Haomian Zheng
Huawei Technologies
Email: zhenghaomian@huawei.com

Italo Busi
Huawei Technologies
Email: Italo.Busi@huawei.com

Nicola Sambo
Scuola Superiore Sant'Anna
Email: nicosambo@gmail.com

Giovanni Martinelli
Cisco
Email: giomarti@cisco.com

Esther Le Rouzic
Orange
Email: esther.lerouzic@orange.com

Julien Meuric
Orange

Email: julien.meuric@orange.com

Sergio Belotti
Nokia

Email: Sergio.belotti@nokia.com

Griseri Enrico
Nokia

Email: Enrico.Griseri@nokia.com

Gert Grammel
Juniper

Email: ggrammel@juniper.net

Authors' Addresses

Young Lee
SKKU (Sung Kyun Kwan University)

Email: younglee.tx@gmail.com

Jean-Luc Auge
Orange

Email: jeanluc.auge@orange.com

Victor Lopez
Telefonica

Email: victor.lopezalvarez@telefonica.com

G. Galimberti
Cisco

Email: ggalimbe@cisco.com

Dieter Beller
Nokia

Email: Dieter.Beller@nokia.com