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A YANG model to manage the optical interface parameters for an external  
transponder in a WDM network  
draft-dharini-ccamp-dwdm-if-param-yang-02

## Abstract

This memo defines a Yang model related to the Optical Transceiver parameters characterising coherent 100G and above interfaces. 100G and above Transceivers support coherent modulation, multiple modulation formats, multiple FEC codes including some not yet specified by ITU-T G.698.2 [ITU.G698.2] or any other ITU-T recommendation. More context about the state of the Coherent transceivers is described in draft-many-coherent-DWDM-if-control. Use cases are described in draft-ietf-ccamp-flexi-grid-fwk

The Yang model defined in this memo can be used for Optical Parameters monitoring and/or configuration of the endpoints of a multi-vendor IaDI optical link.

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#### 1. Introduction

This memo defines a Yang model that translates and obsolete the SNMP mib module defined in draft-galikunze-ccamp-dwdm-if-snmp-mib for managing single channel optical interface parameters of DWDM applications, using the approach specified in G.698.2. This model

supports parameters to characterize coherent transceivers found in current implementations to specify the mode of operation. As application identifiers like those specified in ITU-T G.874.1 [ITU.G874.1] are not available we use mode templates instead. A mode template describes transceiver characteristics in detail and can be identified by a mode-id.

This draft refers and supports the draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk and draft-many-coherent-DWDM-if-control.

The YANG model describing and extending the optical parameters allows different vendors and operators to retrieve, provision and exchange information across the multi-vendor IaDI interfaces in an abstract manner.

The concept introduced by this YANG model is the notion of a mode. A mode is a combination of parameters or parameter ranges that is supported by a transceiver. As an example, operating a device in QPSK mode may use a different FEC and requires less OSNR to reach the FEC limit than the same transceiver operating in QAM16 mode. Given the number of parameters and their possible combinations it is important for vendors to be able to qualify a set of combinations which is the basis to define a mode. The YANG model furthermore provides means to selecting one mode as current-mode from that pre-defined list of modes supported by the transceiver module. Once selected, current-opt-if-och-mode-params provide the means to configure specific parameters at run time and retrieve actual parameters from the module. For example, the frequency is a parameter that can be set within min/max boundaries set by the current mode. Laser Temperature however is a read-only parameter available at run-time that can be checked against the mode boundaries and may trigger an event.

## 2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

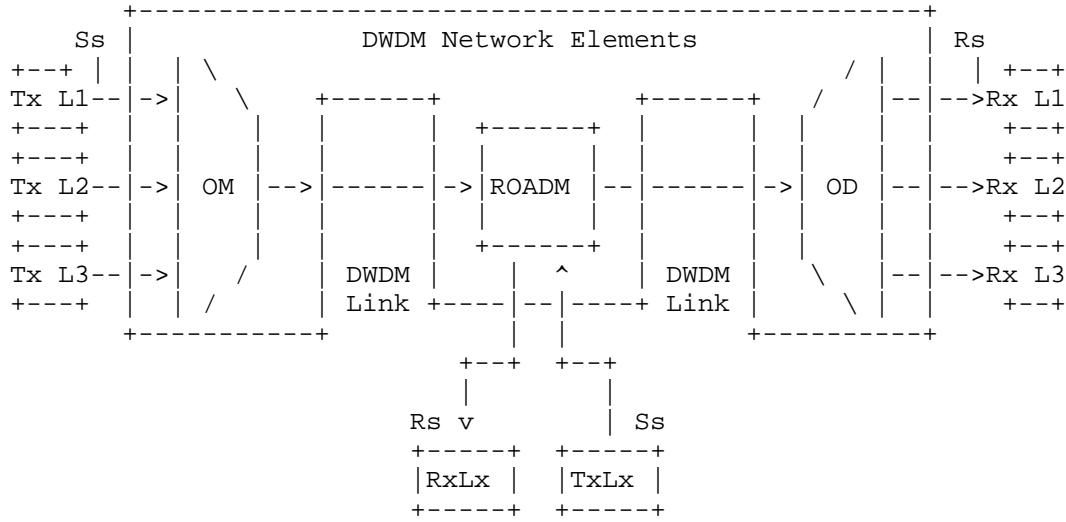
This memo specifies a Yang model for optical interfaces.

## 3. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. In the description of OIDs the convention: Set (S) Get (G) and Trap (T) conventions will describe the action allowed by the parameter.

#### 4. Overview

Figure 1 shows a set of reference points, for single-channel connection between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an OM and an OD (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more OADMs.



Ss = reference point at the DWDM network element tributary output  
Rs = reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: External transponder in WDM networks

##### 4.1. Optical Parameters Description

The link between the external transponders through a WDM network media channels are managed at the edges, i.e. at the transmitters (Tx) and receivers (Rx) attached to the S and R reference points respectively.

Definitions of the optical parameters are provided below to increase the readability of the document.

## 4.1.1. Parameters at Ss

## output-power:

The mean launched power at Ss is the average power (in dBm) of a pseudo-random data sequence coupled into the DWDM link.

## central frequency:

This parameter indicates the Central frequency value that Ss and Rs will be set to work (in THz)

## 4.1.2. Interface at point Rs

## input-power:

The average received power (in dBm) at point Rs.

## Curr-OSNR:

Current Optical Signal to Noise Ratio (OSNR) estimated at Rx Transceiver port.

## Curr-q-factor:

"Q" factor estimated at Rx Transceiver port.

## 4.2. Use Cases

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

## 4.3. Optical Interface for external transponder in a WDM network

The ietf-ext-xponder-wdm-if is an augment to the ietf-interface. It allows the user to set the operating mode of transceivers as well as other operational parameters. The module provides also threshold settings and notifications to supervise measured parameters and notify the client.

```

module: ietf-ext-xponder-wdm-if
augment /if:interfaces/if:interface:
  +--rw optIfOChRsSs
    +--rw if-current-mode
      | +--ro mode-id?                string
      | +--ro min-central-frequency? uint32
      | +--ro max-central-frequency? uint32
      | +--ro min-input-power?       dbm-t
      | +--ro max-input-power?       dbm-t
      | +--ro min-output-power?      dbm-t
      | +--ro max-output-power?      dbm-t
      | +--ro osnr-margin?           int32
      | +--ro q-margin?              int32
      | +--ro fec-info?              string

```

```

|   +--ro fec-bitrate?                string
|   +--ro fec-gain?                  string
|   +--rw fec-ber-mantissa-threshold? uint32
|   +--rw fec-ber-exponent-threshold? int32
|   +--ro number-of-lanes?           uint32
|   +--ro min-laser-temperature?     int32
|   +--ro max-laser-temperature?     int32
|   +--ro min-rx-optical-power?      dbm-t
|   +--ro max-rx-optical-power?      dbm-t
|   +--ro min-chromatic-dispersion?  int32
|   +--ro max-chromatic-dispersion?  int32
|   +--ro min-diff-group-delay?      int32
|   +--ro max-diff-group-delay?      int32
|   +--ro modulation-format?         string
|   +--rw bits-per-symbol?           uint32
|   +--rw num-symbols-in-alphabet?    uint32
|   +--rw symbols-index?             uint32
|   +--ro i-center?                  int32
|   +--ro q-center?                  int32
|   +--ro i-noise-variance?          int32
|   +--ro q-noise-variance?          int32
|   +--ro a-noise-variance?          int32
|   +--ro p-noise-variance?          int32
+--ro if-supported-mode
|   +--ro number-of-modes-supported?  uint32
|   +--ro mode-list* [mode-id]
|       +--ro mode-id                string
|       +--ro min-central-frequency?  uint32
|       +--ro max-central-frequency?  uint32
|       +--ro min-input-power?        dbm-t
|       +--ro max-input-power?        dbm-t
|       +--ro min-output-power?       dbm-t
|       +--ro max-output-power?       dbm-t
|       +--ro osnr-margin?            int32
|       +--ro q-margin?               int32
|       +--ro fec-info?               string
|       +--ro fec-bitrate?            string
|       +--ro fec-gain?               string
|       +--ro fec-ber-mantissa-threshold? uint32
|       +--ro fec-ber-exponent-threshold? int32
|       +--ro number-of-lanes?        uint32
|       +--ro min-laser-temperature?  int32
|       +--ro max-laser-temperature?  int32
|       +--ro min-rx-optical-power?    dbm-t
|       +--ro max-rx-optical-power?    dbm-t
|       +--ro min-chromatic-dispersion? int32
|       +--ro max-chromatic-dispersion? int32
|       +--ro min-diff-group-delay?    int32

```

```

|      +--ro max-diff-group-delay?          int32
|      +--ro modulation-format?            string
|      +--ro bits-per-symbol?              uint32
|      +--ro num-symbols-in-alphabet?      uint32
|      +--ro symbols-index?                uint32
|      +--ro i-center?                      int32
|      +--ro q-center?                      int32
|      +--ro i-noise-variance?              int32
|      +--ro q-noise-variance?              int32
|      +--ro a-noise-variance?              int32
|      +--ro p-noise-variance?              int32
+--rw current-opt-if-och-mode-params
|   +--rw mode-id?                          string
|   +--ro osnr-margin?                      int32
|   +--ro q-margin?                        int32
|   +--rw central-frequency?                uint32
|   +--rw output-power?                    int32
|   +--ro input-power?                     int32
|   +--rw min-fec-ber-mantissa-threshold?  uint32
|   +--rw min-fec-ber-exponent-threshold?  int32
|   +--rw max-fec-ber-mantissa-threshold?  uint32
|   +--rw max-fec-ber-exponent-threshold?  int32
|   +--rw number-of-tcas-supported?         uint32
|   +--rw mode-list* [tca-type]
|   |   +--rw tca-type                      opt-if-och-tca-types
|   |   +--rw min-threshold?                int32
|   |   +--rw max-threshold?                int32
|   +--ro cur-osnr?                        int32
|   +--ro cur-q-factor?                    int32
|   +--ro uncorrected-words?                uint64
|   +--ro fec-ber-mantissa?                 uint32
|   +--ro fec-ber-exponent?                 int32
notifications:
+---n opt-if-och-central-frequency-change
|   +--ro if-name?    -> /if:interfaces/interface/name
|   +--ro new-opt-if-och-central-frequency
|       +--ro central-frequency?          uint32
+---n opt-if-och-mode-change
|   +--ro if-name?    -> /if:interfaces/interface/name
|   +--ro mode-id?    string
+---n opt-if-och-min-tca
|   +--ro if-name?    -> /if:interfaces/interface/name
|   +--ro tca-type?   opt-if-och-tca-types

```

## 5. Structure of the Yang Module

ietf-ext-xponder-wdm-if is a top level model for the support of this feature.

## 6. Yang Module

The ietf-ext-xponder-wdm-if is defined as an extension to ietf interfaces.



```
<CODE BEGINS> file "ietf-ext-xponder-wdm-if.yang"

module ietf-ext-xponder-wdm-if {
  namespace "urn:ietf:params:xml:ns:yang:ietf-ext-xponder-wdm-if";
  prefix ietf-ext-xponder-wdm-if;

  import ietf-interfaces {
    prefix if;
  }

  organization
    "IETF CCAMP
     Working Group";

  contact
    "WG Web:  <http://tools.ietf.org/wg/ccamp/>
     WG List: <mailto:ccamp@ietf.org>

     Editor:  Dharini Hiremagalur
              <mailto:dharinih@juniper.net>";

  description
    "This module contains a collection of YANG definitions for
     configuring Optical interfaces.

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     as authors of the code.  All rights reserved.

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     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 "2017-03-06" {
    description
      "Revision 1.0";
    reference
      "";
  }
  revision "2016-03-17" {
    description
      "Initial revision.";
    reference
      "";
  }
}
```

```
typedef dbm-t {
    type decimal64 {
        fraction-digits 2;
        range "-50..-30 | -10..5 | 10000000";
    }
    description "
        Amplifier Power in dBm ";
}
typedef opt-if-och-tca-types {

    type enumeration {
        enum min-tx-power-tca {
            description " The min tx power tca";
        }
        enum max-tx-power-tca {
            description " The min tx power tca";
        }
        enum min-rx-power-tca{
            description " The min tx power tca";
        }
        enum max-rx-power-tca{
            description " The min tx power tca";
        }
        enum min-frequency-offset-tca{
            description " Min Frequency offset tca";
        }
        enum max-frequency-offset-tca{
            description " Max Frequency offset tca";
        }
        enum min-osnr-tca{
            description " Min OSNR tca";
        }
        enum max-osnr-tca{
            description " Max OSNR tca";
        }
        enum min-laser-temperature-tca{
            description " The min tx power tca";
        }
        enum max-laser-temperature-tca{
            description " Temperature tca";
        }
        enum min-fec-ber-tca{
            description " Min Pre Fec BER tca";
        }
        enum max-fec-ber-tca{
            description " Max Pre Fec BER tca";
        }
        enum min-q-tca{
```

```
        description "Min Q tca";
    }
    enum max-q-tca {
        description "Max Q tca";
    }
}
description " The different types of TCA's";
}

grouping opt-if-och-power {
    description "Interface optical Power";
    leaf output-power {
        type int32;
        units ".01dbm";
        description "The output power for this interface
                     in .01 dBm.
                     The setting of the output power is
                     optional";
    }

    leaf input-power {
        type int32;
        units ".01dbm";
        config false;
        description "The current input power of this
                     interface";
    }
}

grouping opt-if-och-tca-thresholds {
    description "Thresholds for TCA's";
    leaf tca-type {
        type opt-if-och-tca-types;
        description "type of the TCA eg TX Power";
    }
    leaf min-threshold {
        type int32;
        description " A TCA is generated if the variable is
                     less than this value";
    }

    leaf max-threshold {
        type int32;
        description " A TCA is generated if the variable is
                     more than this value";
    }
}
```

```
grouping opt-if-och-fec {
    description "Fec info";
    leaf fec-info {
        type string {
            length "1..255";
        }
        config false;
        description
            "Fec Type - eg GFEC";
    }
    leaf fec-bitrate {
        type string {
            length "1..255";
        }
        config false;
        description
            "Fec Overhead rate ";
    }
    leaf fec-gain {
        type string {
            length "1..255";
        }
        config false;
        description
            "Fec Overhead rate ";
    }
    leaf fec-ber-mantissa-threshold {
        type uint32;
        description " Mantissa of the FEC BER threshold";
    }
    leaf fec-ber-exponent-threshold {
        type int32;
        description " Exponent of the FEC BER threshold";
    }
}

grouping opt-if-och-central-frequency {
    description "Interface Central Frequency";
    leaf central-frequency {
        type uint32;
        description " This parameter indicates the frequency
            of this interface ";
    }
}

grouping opt-if-och-constellation {
    description "Optical constellation parameters";
```

```
leaf i-center {
    type int32;
    units ".0001";
    config false;
    description "The In-phase coordinate of the selected
                constellation symbol for this mode";
}
leaf q-center {
    type int32;
    units ".0001";
    config false;
    description "The Quadrature coordinate of the selected
                constellation symbol for this mode";
}
leaf i-noise-variance {
    type int32;
    units ".001";
    config false;
    description "The Variance of the in-phase noise
                component for this mode";
}
leaf q-noise-variance {
    type int32;
    units ".001";
    config false;
    description "The Variance of the quadrature noise
                component for this mode";
}
leaf a-noise-variance {
    type int32;
    units ".001";
    config false;
    description "The Variance of the radial noise
                component for this mode";
}
leaf p-noise-variance {
    type int32;
    units ".001";
    config false;
    description "The Variance of the phase noise
                component for this mode";
}
}

grouping opt-if-och-modulation-params {
    description "Optical modulation parameters for the lane";
    leaf modulation-format {
        type string {
```

```
        length "1..255";
    }
    config false;
    description
        "Modulation format for this mode";
}
leaf bits-per-symbol {
    type uint32;
    description " This parameter the bits per symbol for
        this mode.";
}
leaf num-symbols-in-alphabet {
    type uint32;
    description " This parameter the bits per symbol for
        this mode.";
}
leaf symbols-index {
    type uint32;
    description " This parameter is the symbol index this
        mode.";
}
}
uses opt-if-och-constellation;
}

grouping opt-if-och-lane-param {
    description "Optical parameters for the lane";
    leaf number-of-lanes {
        type uint32;
        config false;
        description
            "Number of optical lanes of this interface";
    }
    leaf min-laser-temperature {
        type int32;
        units ".01C";
        config false;
        description
            "Minimum Laser Temperature of this mode for
            this interface";
    }
    leaf max-laser-temperature {
        type int32;
        units ".01C";
        config false;
    }
}
```

```
        description
            "Maximum Laser Temperature of this mode for
             this interface";
    }
    leaf min-rx-optical-power {
        type dbm-t;
        config false;
        description
            "Minimum rx optical power of this mode for
             this interface";
    }
    leaf max-rx-optical-power {
        type dbm-t;
        config false;
        description
            "Maximum rx optical power of this mode for
             this interface";
    }
    leaf min-chromatic-dispersion {
        type int32;
        config false;
        description
            "Minimum chromatic dispersion of this mode
             for this interface";
    }
    leaf max-chromatic-dispersion {
        type int32;
        config false;
        description
            "Maximum chromatic dispersion of this
             mode for this interface";
    }
    leaf min-diff-group-delay {
        type int32;
        config false;
        description
            "Minimum Differential group delay of this
             mode for this interface";
    }
    leaf max-diff-group-delay {
        type int32;
        config false;
        description
            "Maximum Differential group delay of this
             mode for this interface";
    }
    uses opt-if-och-modulation-params;
}
```

```
grouping opt-if-och-tca-list {
  description "List of TCA's.";
  leaf number-of-tcas-supported {
    type uint32;
    description "Number of tcas
                  supported by this interface";
  }
  list mode-list {
    key "tca-type";
    description "List of the tcas";
    uses opt-if-och-tca-thresholds;
  }
}

grouping opt-if-och-fec-tca-thresholds {
  description "Pre FEC BER Thresholds for TCA's";
  leaf min-fec-ber-mantissa-threshold {
    type uint32;
    description " Min Mantissa of the FEC BER threshold";
  }
  leaf min-fec-ber-exponent-threshold {
    type int32;
    description " Min Exponent of the FEC BER threshold";
  }
  leaf max-fec-ber-mantissa-threshold {
    type uint32;
    description " Max Mantissa of the FEC BER threshold";
  }
  leaf max-fec-ber-exponent-threshold {
    type int32;
    description " Max Exponent of the FEC BER threshold";
  }
}

grouping opt-if-och-mode-params {
  description "OCh mode parameters.";
  leaf mode-id {
    type string {
      length "1..255";
    }
    description
      "Id for the OCh mode template";
  }
}
```



```
    leaf osnr-margin {
        type int32;
        units "dB";
        config false;
        description " OSNR margin to FEC threshold";
    }
    leaf q-margin {
        type int32;
        units "dB";
        config false;
        description " Q-Factor margin to FEC threshold";
    }
    uses opt-if-och-central-frequency;
    uses opt-if-och-power;
    uses opt-if-och-fec-tca-thresholds;
    uses opt-if-och-tca-list;
}

grouping opt-if-och-statistics {
    description "OCh statistics.";
    leaf cur-osnr {
        type int32;
        units "dB";
        config false;
        description " OSNR margin to FEC threshold";
    }
    leaf cur-q-factor {
        type int32;
        units "dB";
        config false;
        description " Q-Factor of the interface";
    }
    leaf uncorrected-words {
        type uint64;
        config false;
        description " Post FEC errored words";
    }
    leaf fec-ber-mantissa {
        type uint32;
        config false;
        description " Pre fec FEC errored words mantissa";
    }
    leaf fec-ber-exponent {
        type int32;
        config false;
        description " Pre fec FEC errored words exponent";
    }
}
```

```
}

grouping opt-if-och-mode {
  description "OCh mode template.";
  leaf mode-id {
    type string {
      length "1..255";
    }
    config false;
    description
      "Id for the OCh mode template";
  }
  leaf min-central-frequency {
    type uint32;
    config false;
    description "This parameter indicates the minimum
      frequency for this template ";
  }
  leaf max-central-frequency {
    type uint32;
    config false;
    description "This parameter indicates the minimum
      frequency for this template ";
  }
  leaf min-input-power {
    type dbm-t;
    config false;
    description "The minimum input power of this
      interface";
  }
  leaf max-input-power {
    type dbm-t;
    config false;
    description "The maximum input power of this
      interface";
  }
  leaf min-output-power {
    type dbm-t;
    config false;
    description "The minimum output power of this
      interface";
  }
  leaf max-output-power {
    type dbm-t;
    config false;
    description "The maximum output power of this
      interface";
  }
}
```

```
        leaf osnr-margin {
            type int32;
            units "dB";
            config false;
            description "OSNR margin to FEC threshold";
        }
        leaf q-margin {
            type int32;
            units "dB";
            config false;
            description "Q-Factor margin to FEC threshold";
        }
        uses opt-if-och-fec;
        uses opt-if-och-lane-param;
    }

    grouping opt-if-och-mode-list {
        description "List of Mode list group.";
        leaf number-of-modes-supported {
            type uint32;
            description "Number of modes
                        supported by this interface";
        }
        list mode-list {
            key "mode-id";
            description "List of the modes ";
            uses opt-if-och-mode;
        }
    }

    notification opt-if-och-central-frequency-change {
        description "A change of Central Frequency has been
                    detected.";
        leaf "if-name" {
            type leafref {
                path "/if:interfaces/if:interface/if:name";
            }
            description "Interface name";
        }
        container new-opt-if-och-central-frequency {
            description "The new Central Frequency of the
                        interface";
            uses opt-if-och-central-frequency;
        }
    }
}
```

```
    }
  }

  notification opt-if-och-mode-change {
    description "A change of Mode Template has been
      detected.";
    leaf "if-name" {
      type leafref {
        path "/if:interfaces/if:interface/if:name";
      }
      description "Interface name";
    }
    leaf mode-id {
      type string {
        length "1..255";
      }
      description "Id for the OCh mode template";
    }
  }
}

notification opt-if-och-min-tca {
  description "A min output TCA notification.";
  leaf "if-name" {
    type leafref {
      path "/if:interfaces/if:interface/if:name";
    }
    description "Interface name";
  }
  leaf tca-type {
    type opt-if-och-tca-types;
    description "Type of TCA for eg min tx power TCA";
  }
}

augment "/if:interfaces/if:interface" {
  description "Parameters for an optical interface";
  container optIfOChRsSs {
    description "RsSs path configuration for an interface";
    container if-current-mode {
      description "Current mode template of the
        interface";
      uses opt-if-och-mode;
    }

    container if-supported-mode {
      config false;
      description "Supported mode list of
```

```
        this interface";
        uses opt-if-och-mode-list;
    }
    container current-opt-if-och-mode-params {
        description "Current parameters of
                    this interface";
        uses opt-if-och-mode-params;
        uses opt-if-och-statistics;
    }
}
}
}

<CODE ENDS>
```

## 7. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operation and content.

## 8. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

URI: urn:ietf:params:xml:ns:yang:ietf-interfaces:ietf-ext-xponder-wdm-if

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC6020].

This document registers a YANG module in the YANG Module Names registry [RFC6020].

prefix: ietf-ext-xponder-wdm-if reference: RFC XXXX

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## Appendix A. Change Log

This optional section should be removed before the internet draft is submitted to the IESG for publication as an RFC.

Note to RFC Editor: please remove this appendix before publication as an RFC.

## Appendix B. Open Issues

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October 22, 2018

A YANG model to manage the optical interface parameters for an external  
transponder in a WDM network  
draft-dharini-ccamp-dwdm-if-param-yang-06

## Abstract

This memo defines a Yang model related to the Optical Transceiver parameters characterising coherent 100G and above interfaces. 100G and above Transceivers support coherent modulation, multiple modulation formats, multiple FEC codes including some not yet specified (or by in phase of specification by) ITU-T G.698.2 [ITU.G698.2] or any other ITU-T recommendation. More context about the state of the Coherent transceivers is described in draft-many-coherent-DWDM-if-control. Use cases are described in RFC7698

The Yang model defined in this memo can be used for Optical Parameters monitoring and/or configuration of the endpoints of a multi-vendor IaDI optical link. The use of this model does not guarantee interworking of transceivers over a DWDM. Optical path feasibility and interoperability has to be determined by means outside the scope of this document. The purpose of this model is to program interface parameters to consistently configure the mode of operation of transceivers.

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## 1. Introduction

This memo defines a Yang model that translates and obsolete the SNMP mib module defined in draft-galikunze-ccamp-dwdm-if-snmp-mib for managing single channel optical interface parameters of DWDM applications, using the approach specified in G.698.2. This model supports parameters to characterize coherent transceivers found in current implementations to specify the mode of operation. As application identifiers like those specified in ITU-T G.874.1 [ITU.G874.1] are not available we use mode templates instead. A mode template describes transceiver characteristics in detail and can be identified by a mode-id.

This draft refers and supports the RFC7698 and draft-many-coherent-DWDM-if-control.

The YANG model describing and extending the optical parameters allows different vendors and operators to retrieve, provision and exchange information across the multi-vendor IaDI interfaces in an abstract manner.

The they concept introduced by this YANG model is the notion of a mode. A mode is a combination of parameters or parameter ranges that is supported by a transceiver. As an example, operating a device in QPSK mode may use a different FEC and requires less OSNR to reach the FEC limit than the same transceiver operating in QAM16 mode. Given the number of parameters and their possible combinations it is important for vendors to be able to qualify a set of combinations which is the basis to define a mode. The YANG model furthermore provides means to selecting one mode as current-mode from that pre-defined list of modes supported by the transceiver module. Once selected, current-opt-if-och-mode-params provide the means to configure specific parameters at run time and retrieve actual parameters from the module. For example, the frequency is a parameter that can be set within min/max boundaries set by the current mode. Laser Temperature however is a ro parameter available at run-time that can be checked against the mode boundaries and may trigger an event.

## 2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

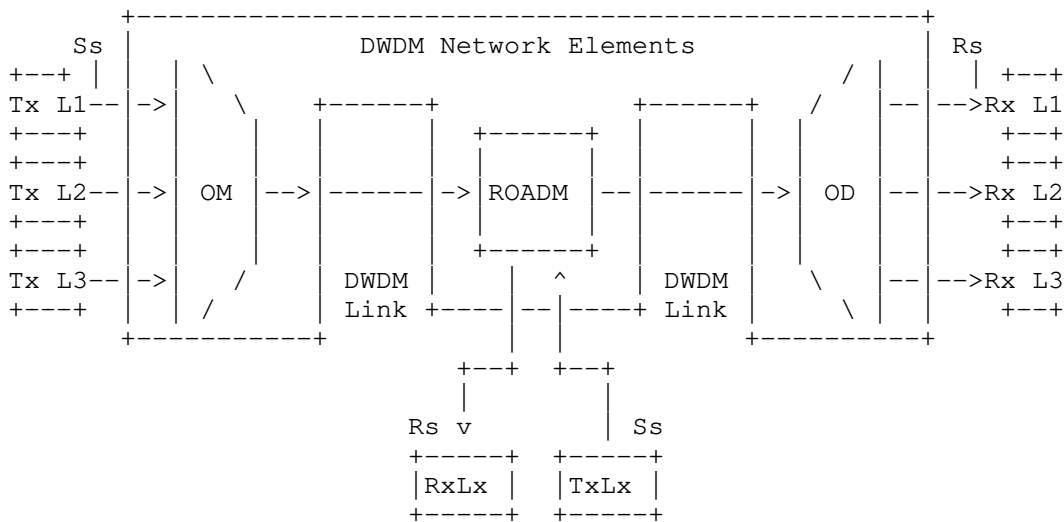
This memo specifies a Yang model for optical interfaces.

### 3. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. In the description of OIDs the convention: Set (S) Get (G) and Trap (T) conventions will describe the action allowed by the parameter.

### 4. Overview

Figure 1 shows a set of reference points, for single-channel connection between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an OM and an OD (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more OADMs.



Ss = reference point at the DWDM network element tributary output  
Rs = reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: External transponder in WDM networks

#### 4.1. Optical Parameters Description

The link between the external transponders through a WDM network media channels are managed at the edges, i.e. at the transmitters (Tx) and receivers (Rx) attached to the S and R reference points respectively.

Definitions of the optical parameters are provided below to increase the readability of the document.

##### 4.1.1. Parameters at Ss

output-power:

The mean launched power at Ss is the average power (in dBm) of a pseudo-random data sequence coupled into the DWDM link.

central frequency:

This parameter indicates the Central frequency value that Ss and Rs will be set to work (in THz)

##### 4.1.2. Interface at point Rs

input-power:

The average received power (in dBm) at point Rs.

Curr-OSNR:

Current Optical Signal to Noise Ratio (OSNR) estimated at Rx Transceiver port.

Curr-q-factor:

"Q" factor estimated at Rx Transceiver port.

#### 4.2. Use Cases

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

#### 4.3. Optical Interface for external transponder in a WDM network

The ietf-ext-xponder-wdm-if is an augment to the ietf-interface. It allows the user to set the operating mode of transceivers as well as other operational parameters. The module provides also threshold settings and notifications to supervise measured parameters and notify the client.

```
module: ietf-ext-xponder-wdm-if
augment /if:interfaces/if:interface:
  +--rw optIfOChRsSs
  +--rw if-current-mode
```

```

+---ro mode-id?                string
+---ro min-central-frequency?   uint32
+---ro max-central-frequency?   uint32
+---ro min-input-power?         dbm-t
+---ro max-input-power?         dbm-t
+---ro min-output-power?        dbm-t
+---ro max-output-power?        dbm-t
+---ro osnr-margin?             int32
+---ro q-margin?                int32
+---ro fec-info?                string
+---ro fec-bitrate?             string
+---ro fec-gain?                string
+---rw fec-ber-mantissa-threshold? uint32
+---rw fec-ber-exponent-threshold? int32
+---ro number-of-lanes?         uint32
+---ro min-laser-temperature?    int32
+---ro max-laser-temperature?    int32
+---ro min-rx-optical-power?     dbm-t
+---ro max-rx-optical-power?     dbm-t
+---ro min-chromatic-dispersion? int32
+---ro max-chromatic-dispersion? int32
+---ro min-diff-group-delay?     int32
+---ro max-diff-group-delay?     int32
+---ro modulation-format?        string
+---rw bits-per-symbol?          uint32
+---rw num-symbols-in-alphabet?   uint32
+---rw symbols-index?            uint32
+---ro i-center?                int32
+---ro q-center?                int32
+---ro i-noise-variance?         int32
+---ro q-noise-variance?         int32
+---ro a-noise-variance?         int32
+---ro p-noise-variance?         int32
+---ro if-supported-mode
+---ro number-of-modes-supported? uint32
+---ro mode-list* [mode-id]
    +---ro mode-id                string
    +---ro min-central-frequency?   uint32
    +---ro max-central-frequency?   uint32
    +---ro min-input-power?         dbm-t
    +---ro max-input-power?         dbm-t
    +---ro min-output-power?        dbm-t
    +---ro max-output-power?        dbm-t
    +---ro osnr-margin?             int32
    +---ro q-margin?                int32
    +---ro fec-info?                string
    +---ro fec-bitrate?             string
    +---ro fec-gain?                string

```



```

    +--ro fec-ber-mantissa-threshold? uint32
    +--ro fec-ber-exponent-threshold? int32
    +--ro number-of-lanes? uint32
    +--ro min-laser-temperature? int32
    +--ro max-laser-temperature? int32
    +--ro min-rx-optical-power? dbm-t
    +--ro max-rx-optical-power? dbm-t
    +--ro min-chromatic-dispersion? int32
    +--ro max-chromatic-dispersion? int32
    +--ro min-diff-group-delay? int32
    +--ro max-diff-group-delay? int32
    +--ro modulation-format? string
    +--ro bits-per-symbol? uint32
    +--ro num-symbols-in-alphabet? uint32
    +--ro symbols-index? uint32
    +--ro i-center? int32
    +--ro q-center? int32
    +--ro i-noise-variance? int32
    +--ro q-noise-variance? int32
    +--ro a-noise-variance? int32
    +--ro p-noise-variance? int32
+--rw current-opt-if-och-mode-params
    +--rw mode-id? string
    +--ro osnr-margin? int32
    +--ro q-margin? int32
    +--rw central-frequency? uint32
    +--rw output-power? int32
    +--ro input-power? int32
    +--rw min-fec-ber-mantissa-threshold? uint32
    +--rw min-fec-ber-exponent-threshold? int32
    +--rw max-fec-ber-mantissa-threshold? uint32
    +--rw max-fec-ber-exponent-threshold? int32
    +--rw number-of-tcas-supported? uint32
    +--rw mode-list* [tca-type]
        +--rw tca-type opt-if-och-tca-types
        +--rw min-threshold? int32
        +--rw max-threshold? int32
    +--ro cur-osnr? int32
    +--ro cur-q-factor? int32
    +--ro uncorrected-words? uint64
    +--ro fec-ber-mantissa? uint32
    +--ro fec-ber-exponent? int32

```

notifications:

```

+---n opt-if-och-central-frequency-change
    +--ro if-name? -> /if:interfaces/interface/name
    +--ro new-opt-if-och-central-frequency
        +--ro central-frequency? uint32

```

```
+---n opt-if-och-mode-change
|   +---ro if-name?   -> /if:interfaces/interface/name
|   +---ro mode-id?               string
+---n opt-if-och-min-tca
|   +---ro if-name?   -> /if:interfaces/interface/name
|   +---ro tca-type?   opt-if-och-tca-types
```

## 5. Structure of the Yang Module

ietf-ext-xponder-wdm-if is a top level model for the support of this feature.

## 6. Yang Module

The ietf-ext-xponder-wdm-if is defined as an extension to ietf interfaces.

<CODE BEGINS> file "ietf-ext-xponder-wdm-if.yang"

```
module ietf-ext-xponder-wdm-if {
  namespace "urn:ietf:params:xml:ns:yang:ietf-ext-xponder-wdm-if";
  prefix ietf-ext-xponder-wdm-if;

  import ietf-interfaces {
    prefix if;
  }

  organization
    "IETF CCAMP
    Working Group";

  contact
    "WG Web:  <http://tools.ietf.org/wg/ccamp/>
    WG List:  <mailto:ccamp@ietf.org>

    Editor:   Dharini Hiremagalur
              <mailto:dharith@juniper.net>";

  description
    "This module contains a collection of YANG definitions for
    configuring Optical interfaces.

    Copyright (c) 2016 IETF Trust and the persons identified
    as authors of the code. All rights reserved."
```

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```
revision "2018-10-22" {
    description
        "Revision 1.2";
    reference
        "";
}

revision "2018-03-06" {
    description
        "Revision 1.1";
    reference
        "";
}

revision "2017-03-06" {
    description
        "Revision 1.0";
    reference
        "";
}
revision "2016-03-17" {
    description
        "Initial revision.";
    reference
        "";
}

typedef dbm-t {
    type decimal64 {
        fraction-digits 2;
        range "-50..-30 | -10..5 | 10000000";
    }
    description "
        Amplifier Power in dBm ";
}
typedef opt-if-och-tca-types {
    type enumeration {
        enum max-laser-linewdt {
```

```

        description " The maximum laser linewidth";
    }
    enum min-tx-power-tca {
        description " The min tx power tca";
    }
    enum max-tx-power-tca {
        description " The min tx power tca";
    }
    enum min-rx-power-tca{
        description " The min tx power tca";
    }
    enum max-rx-power-tca{
        description " The min tx power tca";
    }
    enum max-pol-power-diff-tca{
        description " The power diff. between polariz. tca";
    }
    enum max-pol-skew-diff-tca{
        description " The Skew between the two polariz. tca";
    }
    enum min-frequency-offset-tca{
        description " Min Frequency offset tca";
    }
    enum max-frequency-offset-tca{
        description " Max Frequency offset tca";
    }
    enum min-osnr-tca{
        description " Min OSNR tca";
    }
    enum max-osnr-tca{
        description " Max OSNR tca";
    }
    enum min-laser-temperature-tca{
        description " The min tx power tca";
    }
    enum max-laser-temperature-tca{
        description " Temperature tca";
    }
    enum min-fec-ber-tca{
        description " Min Pre Fec BER tca";
    }
    enum max-fec-ber-tca{
        description " Max Pre Fec BER tca";
    }
    enum min-q-tca{
        description "Min Q tca";
    }
    enum max-q-tca {

```

```

        description "Max Q tca";
    }
}
description " The different types of TCA's";
}

grouping opt-if-och-power {
    description "Interface optical Power";
    leaf output-power {
        type int32;
        units ".01dbm";
        description "The output power for this interface
                    in .01 dBm.
                    The setting of the output power is
                    optional";
    }

    leaf input-power {
        type int32;
        units ".01dbm";
        config false;
        description "The current input power of this
                    interface";
    }
}

grouping opt-if-och-tca-thresholds {
    description "Thresholds for TCA's";
    leaf tca-type {
        type opt-if-och-tca-types;
        description "type of the TCA eg TX Power";
    }
    leaf min-threshold {
        type int32;
        description " A TCA is generated if the variable is
                    less than this value";

    }
    leaf max-threshold {
        type int32;
        description " A TCA is generated if the variable is
                    more than this value";
    }
}

grouping opt-if-och-fec {
    description "Fec info";
}

```

```

        leaf fec-info {
            type string {
                length "1..255";
            }
            config false;
            description
                "Fec Type - eg GFEC";
        }
        leaf fec-bitrate {
            type string {
                length "1..255";
            }
            config false;
            description
                "Fec Overhead rate ";
        }
        leaf fec-gain {
            type string {
                length "1..255";
            }
            config false;
            description
                "Fec Overhead rate ";
        }
        leaf fec-ber-mantissa-threshold {
            type uint32;
            description " Mantissa of the FEC BER threshold";
        }
        leaf fec-ber-exponent-threshold {
            type int32;
            description " Exponent of the FEC BER threshold";
        }
    }

    grouping opt-if-och-central-frequency {
        description "Interface Central Frequency";
        leaf central-frequency {
            type uint32;
            description " This parameter indicates the frequency
                of this interface ";
        }
    }

    grouping opt-if-och-constellation {
        description "Optical constellation parameters";
        leaf i-center {
            type int32;

```

```

        units ".0001";
        config false;
        description "The In-phase coordinate of the selected
                    constellation symbol for this mode";
    }
    leaf q-center {
        type int32;
        units ".0001";
        config false;
        description "The Quadrature coordinate of the selected
                    constellation symbol for this mode";
    }
    leaf i-noise-variance {
        type int32;
        units ".001";
        config false;
        description "The Variance of the in-phase noise
                    component for this mode";
    }
    leaf q-noise-variance {
        type int32;
        units ".001";
        config false;
        description "The Variance of the quadrature noise
                    component for this mode";
    }
    leaf a-noise-variance {
        type int32;
        units ".001";
        config false;
        description "The Variance of the radial noise
                    component for this mode";
    }
    leaf p-noise-variance {
        type int32;
        units ".001";
        config false;
        description "The Variance of the phase noise
                    component for this mode";
    }
}

grouping opt-if-och-modulation-params {
    description "Optical modulation parameters for the lane";
    leaf modulation-format {
        type string {
            length "1..255";
        }
    }
}

```

```

        config false;
        description
            "Modulation format for this mode";
    }
    leaf bits-per-symbol {
        type uint32;
        description " This parameter the bits per symbol for
            this mode.";
    }
    leaf num-symbols-in-alphabet {
        type uint32;
        description " This parameter the bits per symbol for
            this mode.";
    }
    leaf symbols-index {
        type uint32;
        description " This parameter is the symbol index this
            mode.";
    }
    uses opt-if-och-constellation;
}

grouping opt-if-och-lane-param {
    description "Optical parameters for the lane";
    leaf number-of-lanes {
        type uint32;
        config false;
        description
            "Number of optical lanes of this interface";
    }
    leaf min-laser-temperature {
        type int32;
        units ".01C";
        config false;
        description
            "Minimum Laser Temperature of this mode for
            this interface";
    }
    leaf max-laser-temperature {
        type int32;
        units ".01C";
        config false;
        description
            "Maximum Laser Temperature of this mode for

```



```

        this interface";
    }
    leaf min-rx-optical-power {
        type dbm-t;
        config false;
        description
            "Minimum rx optical power of this mode for
             this interface";
    }
    leaf max-rx-optical-power {
        type dbm-t;
        config false;
        description
            "Maximum rx optical power of this mode for
             this interface";
    }
    leaf min-chromatic-dispersion {
        type int32;
        config false;
        description
            "Minimum chromatic dispersion of this mode
             for this interface";
    }
    leaf max-chromatic-dispersion {
        type int32;
        config false;
        description
            "Maximum chromatic dispersion of this
             mode for this interface";
    }
    leaf min-diff-group-delay {
        type int32;
        config false;
        description
            "Minimum Differential group delay of this
             mode for this interface";
    }
    leaf max-diff-group-delay {
        type int32;
        config false;
        description
            "Maximum Differential group delay of this
             mode for this interface";
    }
    uses opt-if-och-modulation-params;
}

```

```

grouping opt-if-och-tca-list {
  description "List of TCA's.";
  leaf number-of-tcas-supported {
    type uint32;
    description "Number of tcas
                  supported by this interface";
  }
  list mode-list {
    key "tca-type";
    description "List of the tcas";
    uses opt-if-och-tca-thresholds;
  }
}

grouping opt-if-och-fec-tca-thresholds {
  description "Pre FEC BER Thresholds for TCA's";
  leaf min-fec-ber-mantissa-threshold {
    type uint32;
    description " Min Mantissa of the FEC BER threshold";
  }
  leaf min-fec-ber-exponent-threshold {
    type int32;
    description " Min Exponent of the FEC BER threshold";
  }
  leaf max-fec-ber-mantissa-threshold {
    type uint32;
    description " Max Mantissa of the FEC BER threshold";
  }
  leaf max-fec-ber-exponent-threshold {
    type int32;
    description " Max Exponent of the FEC BER threshold";
  }
}

grouping opt-if-och-mode-params {
  description "OCh mode parameters.";
  leaf mode-id {
    type string {
      length "1..255";
    }
    description
      "Id for the OCh mode template";
  }
}

```

```

    leaf osnr-margin {
        type int32;
        units "dB";
        config false;
        description " OSNR margin to FEC threshold";
    }
    leaf q-margin {
        type int32;
        units "dB";
        config false;
        description " Q-Factor margin to FEC threshold";
    }
    uses opt-if-och-central-frequency;
    uses opt-if-och-power;
    uses opt-if-och-fec-tca-thresholds;
    uses opt-if-och-tca-list;
}

grouping opt-if-och-statistics {
    description "OCh statistics.";
    leaf cur-osnr {
        type int32;
        units "dB";
        config false;
        description " OSNR margin to FEC threshold";
    }
    leaf cur-q-factor {
        type int32;
        units "dB";
        config false;
        description " Q-Factor of the interface";
    }
    leaf uncorrected-words {
        type uint64;
        config false;
        description " Post FEC errored words";
    }
    leaf fec-ber-mantissa {
        type uint32;
        config false;
        description " Pre fec FEC errored words mantissa";
    }
    leaf fec-ber-exponent {
        type int32;
        config false;
        description " Pre fec FEC errored words exponent";
    }
}

```

```

}

grouping opt-if-och-mode {
  description "OCh mode template.";
  leaf mode-id {
    type string {
      length "1..255";
    }
    config false;
    description
      "Id for the OCh mode template";
  }
  leaf min-central-frequency {
    type uint32;
    config false;
    description "This parameter indicates the minimum
      frequency for this template ";
  }
  leaf max-central-frequency {
    type uint32;
    config false;
    description "This parameter indicates the minimum
      frequency for this template ";
  }
  leaf min-input-power {
    type dbm-t;
    config false;
    description "The minimum input power of this
      interface";
  }
  leaf max-input-power {
    type dbm-t;
    config false;
    description "The maximum input power of this
      interface";
  }
  leaf min-output-power {
    type dbm-t;
    config false;
    description "The minimum output power of this
      interface";
  }
  leaf max-output-power {
    type dbm-t;
    config false;
    description "The maximum output power of this
      interface";
  }
}

```

```

        leaf osnr-margin {
            type int32;
            units "dB";
            config false;
            description "OSNR margin to FEC threshold";
        }
        leaf q-margin {
            type int32;
            units "dB";
            config false;
            description "Q-Factor margin to FEC threshold";
        }
        uses opt-if-och-fec;
        uses opt-if-och-lane-param;
    }

    grouping opt-if-och-mode-list {
        description "List of Mode list group.";
        leaf number-of-modes-supported {
            type uint32;
            description "Number of modes
                        supported by this interface";
        }
        list mode-list {
            key "mode-id";
            description "List of the modes ";
            uses opt-if-och-mode;
        }
    }

    notification opt-if-och-central-frequency-change {
        description "A change of Central Frequency has been
                    detected.";
        leaf "if-name" {
            type leafref {
                path "/if:interfaces/if:interface/if:name";
            }
            description "Interface name";
        }
        container new-opt-if-och-central-frequency {
            description "The new Central Frequency of the
                        interface";
            uses opt-if-och-central-frequency;
        }
    }

```

```

    }
  }

  notification opt-if-och-mode-change {
    description "A change of Mode Template has been
      detected.";
    leaf "if-name" {
      type leafref {
        path "/if:interfaces/if:interface/if:name";
      }
      description "Interface name";
    }
    leaf mode-id {
      type string {
        length "1..255";
      }
      description "Id for the OCh mode template";
    }
  }
}

notification opt-if-och-min-tca {
  description "A min output TCA notification.";
  leaf "if-name" {
    type leafref {
      path "/if:interfaces/if:interface/if:name";
    }
    description "Interface name";
  }
  leaf tca-type {
    type opt-if-och-tca-types;
    description "Type of TCA for eg min tx power TCA";
  }
}

augment "/if:interfaces/if:interface" {
  description "Parameters for an optical interface";
  container optIfOChRsSs {
    description "RsSs path configuration for an interface";
    container if-current-mode {
      description "Current mode template of the
        interface";
      uses opt-if-och-mode;
    }

    container if-supported-mode {
      config false;
      description "Supported mode list of

```

```
        this interface";
        uses opt-if-och-mode-list;
    }
    container current-opt-if-och-mode-params {
        description "Current parameters of
                    this interface";
        uses opt-if-och-mode-params;
        uses opt-if-och-statistics;
    }
}
}
```

<CODE ENDS>

## 7. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operation and content.

## 8. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

URI: urn:ietf:params:xml:ns:yang:ietf-interfaces:ietf-ext-xponder-wdm-if

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC6020].

This document registers a YANG module in the YANG Module Names registry [RFC6020].

prefix: ietf-ext-xponder-wdm-if reference: RFC XXXX

9. Acknowledgements

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## Appendix A. Change Log

This optional section should be removed before the internet draft is submitted to the IESG for publication as an RFC.

Note to RFC Editor: please remove this appendix before publication as an RFC.

## Appendix B. Open Issues

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Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense  
Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage  
the application code of optical interface parameters in DWDM application  
draft-dharinigert-ccamp-dwdm-if-lmp-04

## Abstract

This memo defines extensions to LMP(rfc4209) for managing Optical parameters associated with Wavelength Division Multiplexing (WDM) systems in accordance with the Interface Application Identifier approach defined in ITU-T Recommendation G.694.1.[ITU.G694.1] and its extensions.

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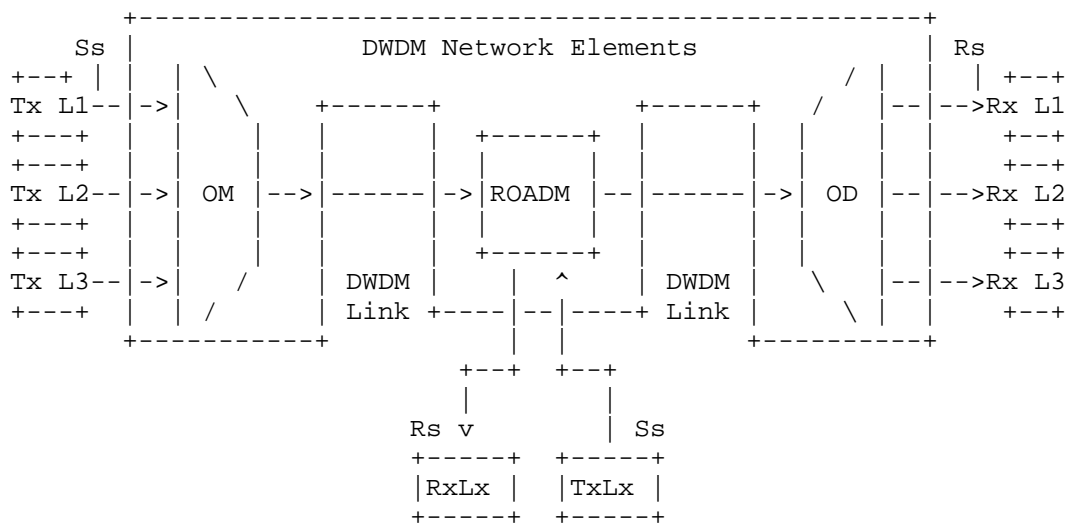
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## 1. Introduction

This extension addresses the use cases described by "draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk-00". LMP [RFC4902] provides link property correlation capabilities that can be used between a transceiver device and an Optical Line System (OLS) device. Link property correlation is a procedure by which, intrinsic parameters and capabilities are exchanged between two ends of a link. Link property correlation as defined in RFC3591 allows either end of the link to supervise the received signal and operate within a commonly understood parameter window. Here the term 'link' refers in particular to the attachment link between OXC and OLS (see Figure 1). The relevant interface parameters are in line with "draft-galikunze-ccamp-dwdm-if-snmplib-01" and "draft-dharini-ccamp-dwdm-if-yang-00".

## 2. DWDM line system

Figure 1 shows a set of reference points (Rs and Ss), for a single-channel connection between transmitter (Tx) and receiver (Rx) devices. Here the DWDM network elements in between those devices include an Optical Multiplexer (OM) and an Optical Demultiplexer (OD). In addition it may include one or more Optical Amplifiers (OA) and one or more Optical Add-Drop Multiplexers (OADM).

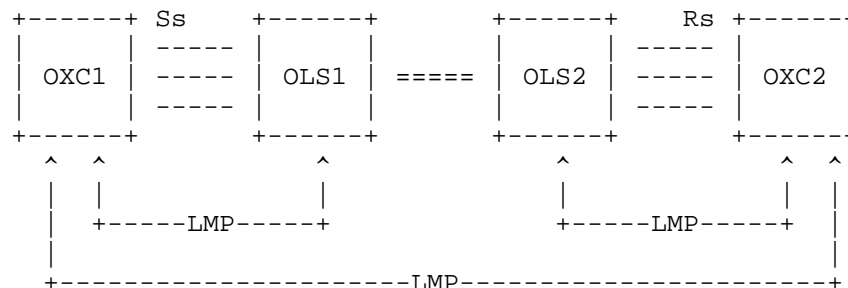


Ss = Sender reference point at the DWDM network element tributary output  
Rs = Receiver reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: Linear Single Channel approach

Figure 2 Extended LMP Model ( from [RFC4209] )



OXC : is an entity that contains transponders  
 OLS : generic optical system, it can be -  
       Optical Mux, Optical Demux, Optical Add  
       Drop Mux, Amplifier etc.  
 OLS to OLS : represents the Optical Multiplex section  
             <xref target="ITU.G709"/>  
 Rs/Ss : reference points in between the OXC and the OLS

Figure 2: Extended LMP Model

### 3. Use Cases

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

### 4. Extensions to LMP-WDM Protocol

This document defines extensions to [RFC4209] to allow a set of characteristic parameters, to be exchanged between a router or optical switch and the optical line system to which it is attached. In particular, this document defines additional Data Link sub-objects to be carried in the LinkSummary message defined in [RFC4204] and [RFC6205]. The OXC and OLS systems may be managed by different Network management systems and hence may not know the capability and status of their peer. These messages and their usage are defined in subsequent sections of this document.



The following new messages are defined for the WDM extension for  
ITU-T G.698.2 [ITU.G698.2]/ITU-T G.698.1 [ITU.G698.1]/  
ITU-T G.959.1 [ITU.G959.1]

- OCh\_General (sub-object Type = TBA)
- OCh\_ApplicationIdentifier (sub-object Type = TBA)
- OCh\_Ss (sub-object Type = TBA)
- OCh\_Rs (sub-object Type = TBA)

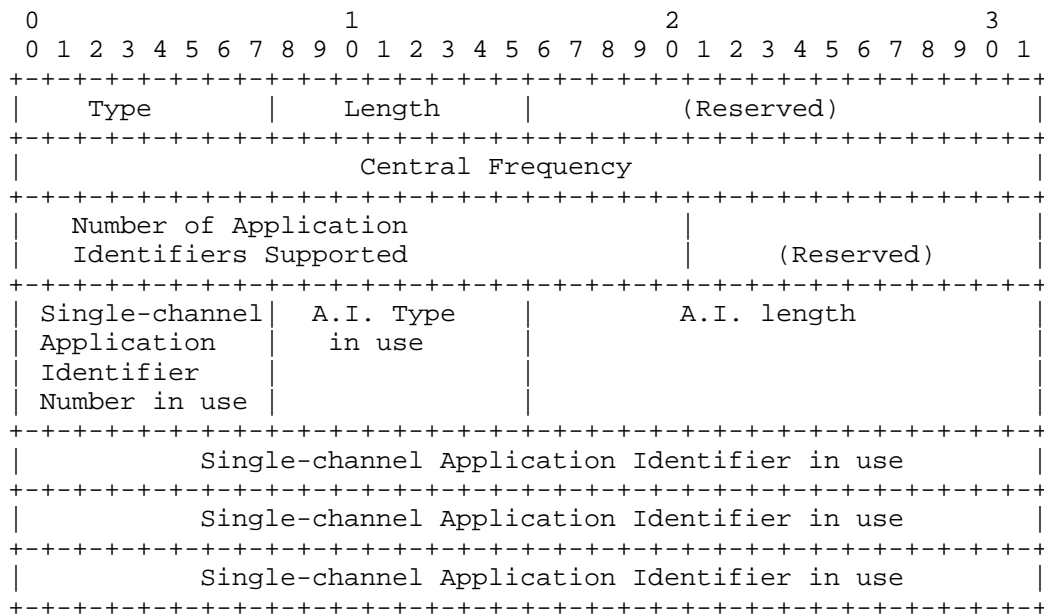
## 5. General Parameters - OCh\_General

These are a set of general parameters as described in [G698.2] and [G.694.1]. Please refer to the "draft-galikunze-ccamp-dwdm-if-snmp-mib-01" and "draft-dharini-ccamp-dwdm-if-yang-00" for more details about these parameters and the [RFC6205] for the wavelength definition.

The general parameters are

1. Central Frequency - (Tera Hz) 4 bytes (see RFC6205 sec.3.2)
2. Number of Application Identifiers (A.I.) Supported
3. Single-channel Application Identifier in use
4. Application Identifier Type in use
5. Application Identifier in use

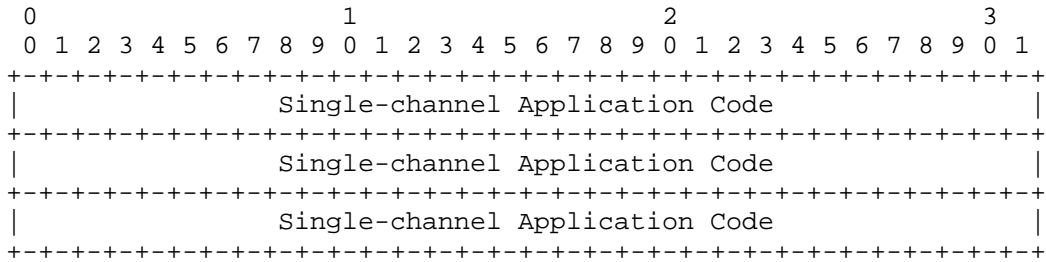
Figure 3: The format of the this sub-object (Type = TBA, Length = TBA) is as follows:



A.I. Type in use: STANDARD, PROPRIETARY

A.I. Type in use: STANDARD

Refer to G.698.2 recommendation : B-DScW-ytz(v)



A.I. Type in use: PROPRIETARY

Note: if the A.I. type = PROPRIETARY, the first 6 Octets of the Application Identifier in use are six characters of the PrintableString must contain the Hexadecimal representation of an OUI (Organizationally Unique Identifier) assigned to the vendor whose implementation generated the Application Identifier; the remaining octets of the PrintableString are unspecified.

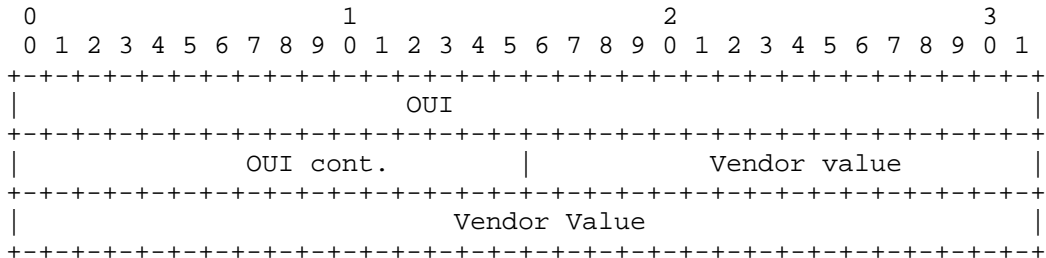


Figure 3: OCh\_General

## 6. ApplicationIdentifier - OCh\_ApplicationIdentifier

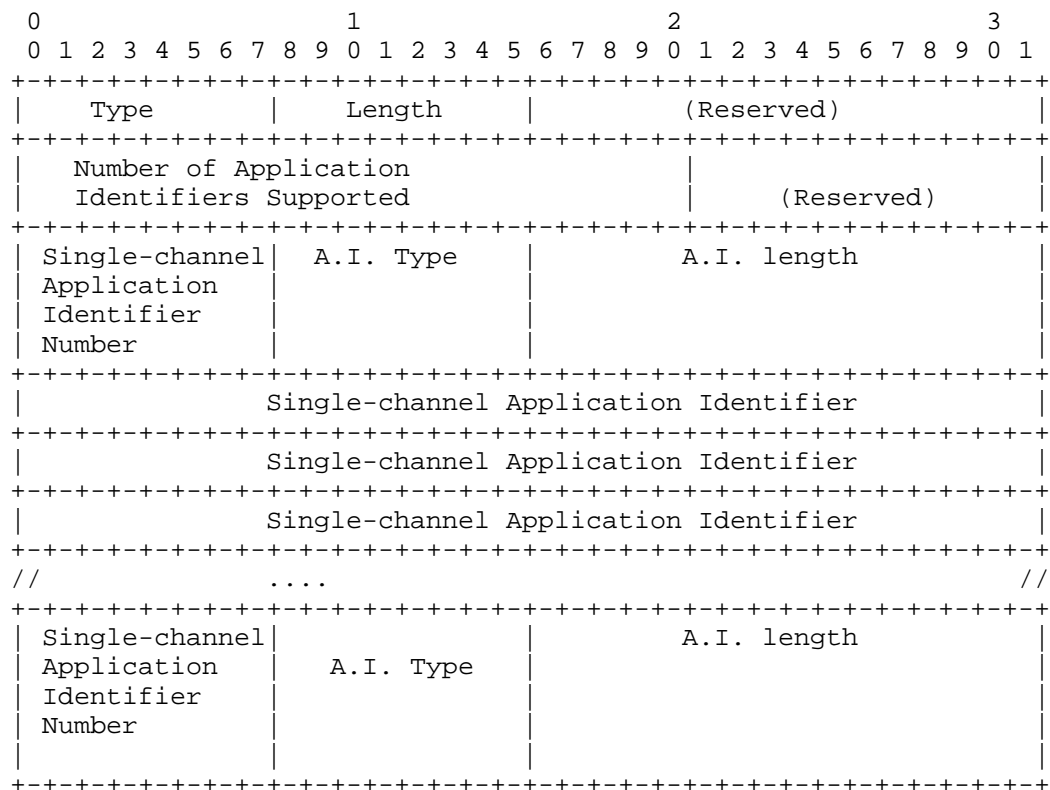
This message is to exchange the application identifiers supported as described in [G698.2]. There can be more than one Application Identifier supported by the transmitter/receiver in the OXC. The number of application identifiers supported is exchanged in the "OCh\_General" message. (from [G698.1]/[G698.2]/[G959.1] and G.874.1)

The parameters are

1. Number of Application Identifiers (A.I.) Supported
2. Single-channel application identifier Number  
uniquely identifies this entry - 8 bits
3. Application Identifier Type (A.I.) (STANDARD/PROPRIETARY)
4. Single-channel application identifier -- 96 bits  
(from [G698.1]/[G698.2]/[G959.1])

- this parameter can have multiple instances as the transceiver can support multiple application identifiers.

Figure 4: The format of the this sub-object (Type = TBA, Length = TBA) is as follows:



```

|           Single-channel Application Identifier           |
+-----+-----+-----+-----+-----+-----+-----+
|           Single-channel Application Identifier           |
+-----+-----+-----+-----+-----+-----+-----+
|           Single-channel Application Identifier           |
+-----+-----+-----+-----+-----+-----+-----+

```

A.I. Type in use: STANDARD, PROPRIETARY

A.I. Type in use: STANDARD

Refer to G.698.2 recommendation : B-DScW-ytz(v)

```

0           1           2           3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+
|           Single-channel Application Code                 |
+-----+-----+-----+-----+-----+-----+-----+
|           Single-channel Application Code                 |
+-----+-----+-----+-----+-----+-----+-----+
|           Single-channel Application Code                 |
+-----+-----+-----+-----+-----+-----+-----+

```

A.I. Type in use: PROPRIETARY

Note: if the A.I. type = PROPRIETARY, the first 6 Octets of the Application Identifier in use are six characters of the PrintableString must contain the Hexadecimal representation of an OUI (Organizationally Unique Identifier) assigned to the vendor whose implementation generated the Application Identifier; the remaining octets of the PrintableString are unspecified.

```

0           1           2           3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+
|           OUI                                             |
+-----+-----+-----+-----+-----+-----+-----+
|           OUI cont.           |           Vendor value   |
+-----+-----+-----+-----+-----+-----+-----+
|           Vendor Value                                             |
+-----+-----+-----+-----+-----+-----+-----+

```

Figure 4: OCh\_ApplicationIdentifier

## 7. OCh\_Ss - OCh transmit parameters

These are the G.698.2 parameters at the Source(Ss reference points). Please refer to "draft-galikunze-ccamp-dwdm-if-snmp-mib-01" for more details about these parameters.

### 1. Output power

Figure 5: The format of the OCh sub-object (Type = TBA, Length = TBA) is as follows:

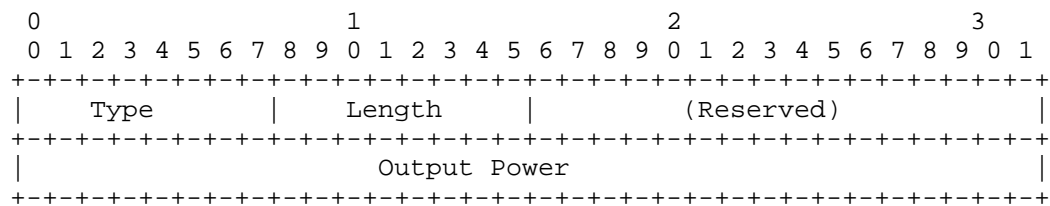


Figure 5: OCh\_Ss transmit parameters

## 8. OCh\_Rs - receive parameters

These are the G.698.2 parameters at the Sink (Rs reference points).

### 1. Current Input Power - (0.1dbm) 4bytes

Figure 6: The format of the OCh receive sub-object (Type = TBA, Length = TBA) is as follows:

The format of the OCh receive/OLS Sink sub-object (Type = TBA, Length = TBA) is as follows:

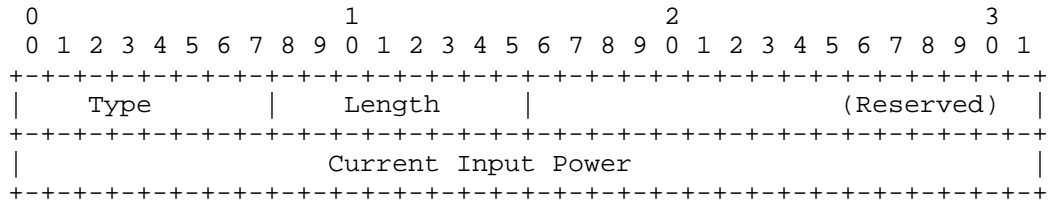


Figure 6: OCh\_Rs receive parameters

## 9. Security Considerations

LMP message security uses IPsec, as described in [RFC4204]. This document only defines new LMP objects that are carried in existing LMP messages, similar to the LMP objects in [RFC:4209]. This document does not introduce new security considerations.

## 10. IANA Considerations

LMP <xref target="RFC4204"/> defines the following name spaces and the ways in which IANA can make assignments to these namespaces:

- LMP Message Type
  - LMP Object Class
  - LMP Object Class type (C-Type) unique within the Object Class
  - LMP Sub-object Class type (Type) unique within the Object Class
- This memo introduces the following new assignments:

LMP Sub-Object Class names:

under DATA\_LINK Class name (as defined in <xref target="RFC4204"/>)

- OCh\_General (sub-object Type = TBA)
- OCh\_ApplicationIdentifier (sub-object Type = TBA)
- OCh\_Ss (sub-object Type = TBA)
- OCh\_Rs (sub-object Type = TBA)

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- [RFC4209] Fredette, A., Ed. and J. Lang, Ed., "Link Management Protocol (LMP) for Dense Wavelength Division Multiplexing (DWDM) Optical Line Systems", RFC 4209, DOI 10.17487/RFC4209, October 2005, <<http://www.rfc-editor.org/info/rfc4209>>.
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October 22, 2018

Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense  
Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage  
the application code of optical interface parameters in DWDM application  
draft-dharinigert-ccamp-dwdm-if-lmp-08

#### Abstract

This memo defines extensions to LMP(rfc4209) for managing Optical parameters associated with Wavelength Division Multiplexing (WDM) systems in accordance with the Interface Application Identifier approach defined in ITU-T Recommendation G.694.1.[ITU.G694.1] and its extensions.

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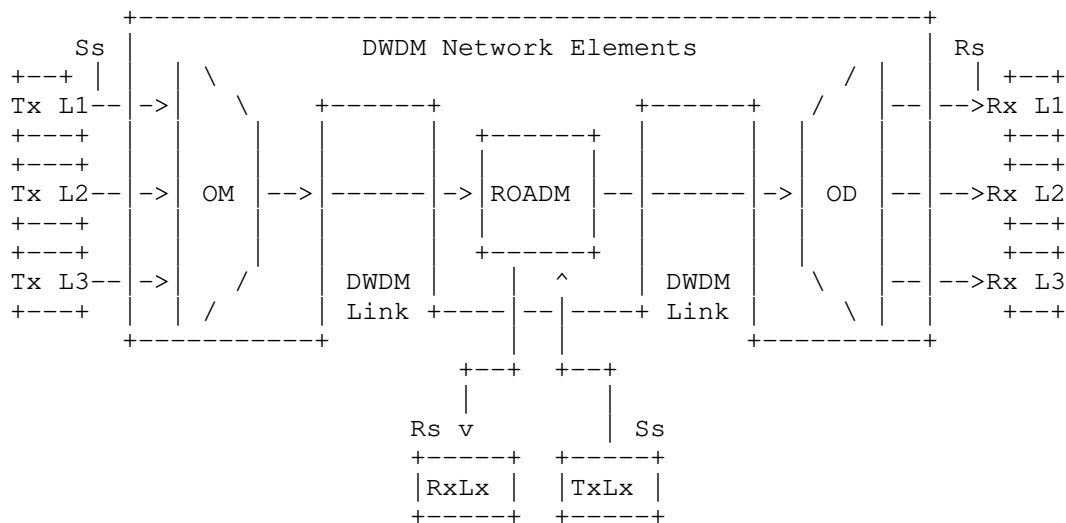
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## 1. Introduction

This extension addresses the use cases described by "draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk". LMP [RFC4902] provides link property correlation capabilities that can be used between a transceiver device and an Optical Line System (OLS) device. Link property correlation is a procedure by which, intrinsic parameters and capabilities are exchanged between two ends of a link. Link property correlation as defined in RFC3591 allows either end of the link to supervise the received signal and operate within a commonly understood parameter window. Here the term 'link' refers in particular to the attachment link between OXC and OLS (see Figure 1). The relevant interface parameters are in line with "draft-dharini-ccamp-dwdm-if-yang".

## 2. DWDM line system

Figure 1 shows a set of reference points (Rs and Ss), for a single-channel connection between transmitter (Tx) and receiver (Rx) devices. Here the DWDM network elements in between those devices include an Optical Multiplexer (OM) and an Optical Demultiplexer (OD). In addition it may include one or more Optical Amplifiers (OA) and one or more Optical Add-Drop Multiplexers (OADM).

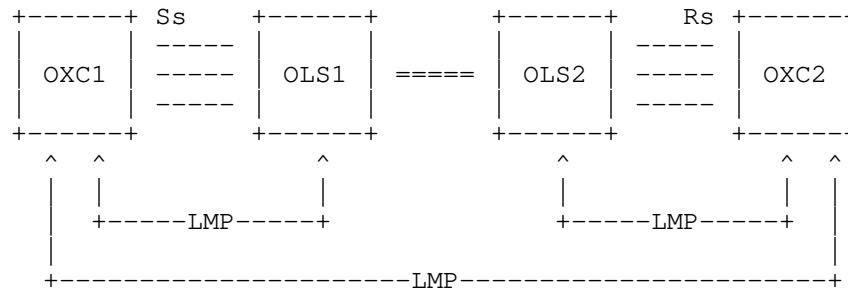


Ss = Sender reference point at the DWDM network element tributary output  
Rs = Receiver reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: Linear Single Channel approach

Figure 2 Extended LMP Model ( from [RFC4209] )



OXC           : is an entity that contains transponders  
 OLS           : generic optical system, it can be -  
               Optical Mux, Optical Demux, Optical Add  
               Drop Mux, Amplifier etc.  
 OLS to OLS   : represents the Optical Multiplex section  
               <xref target="ITU.G709"/>  
 Rs/Ss         : reference points in between the OXC and the OLS

Figure 2: Extended LMP Model

### 3. Use Cases

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

### 4. Extensions to LMP-WDM Protocol

This document defines extensions to [RFC4209] to allow a set of characteristic parameters, to be exchanged between a router or optical switch (e.g. OTN cross connect) and the optical line system to which it is attached. In particular, this document defines additional Data Link sub-objects to be carried in the LinkSummary message defined in [RFC4204] and [RFC6205]. The OXC and OLS systems may be managed by different Network management systems and hence may not know the capability and status of their peer. These messages and their usage are defined in subsequent sections of this document.

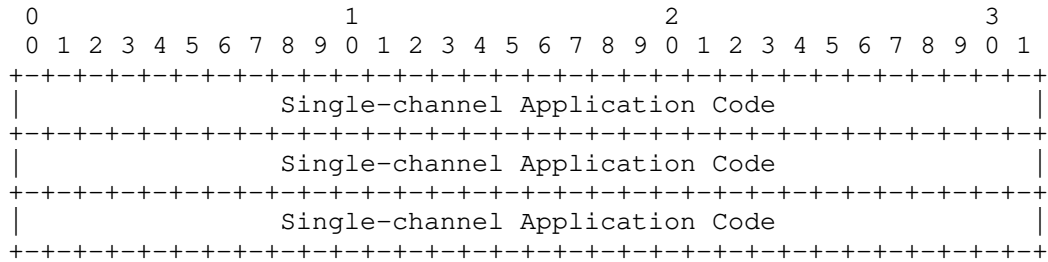
- OCh\_General (sub-object Type = TBA)
- OCh\_ApplicationIdentifier (sub-object Type = TBA)
- OCh\_Ss (sub-object Type = TBA)
- OCh\_Rs (sub-object Type = TBA)

0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9
Type										Length										(Reserved)																			
Central Frequency																																							
Number of Application Identifiers Supported																				(Reserved)																			
Single-channel Application Identifier Number in use										A.I. Type in use										A.I. length																			
Single-channel Application Identifier in use																																							
Single-channel Application Identifier in use																																							
Single-channel Application Identifier in use																																							

A.I. Type in use: STANDARD, PROPRIETARY

A.I. Type in use: STANDARD

Refer to G.698.2 recommendation : B-DScW-ytz(v)



A.I. Type in use: PROPRIETARY

Note: if the A.I. type = PROPRIETARY, the first 6 Octets of the Application Identifier in use are six characters of the PrintableString must contain the Hexadecimal representation of an OUI (Organizationally Unique Identifier) assigned to the vendor whose implementation generated the Application Identifier; the remaining octets of the PrintableString are unspecified.

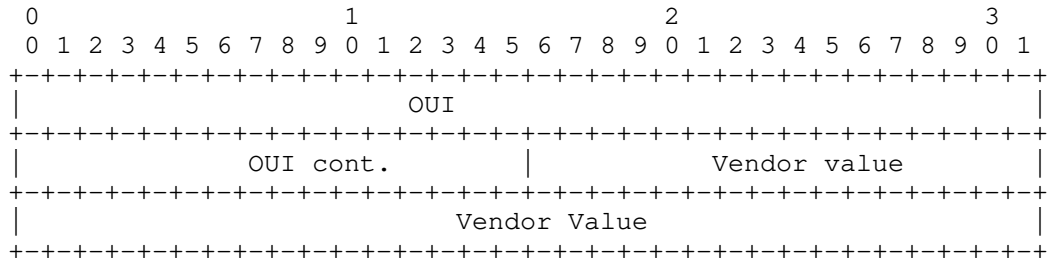


Figure 3: OCh\_General

## 6. ApplicationIdentifier - OCh\_ApplicationIdentifier

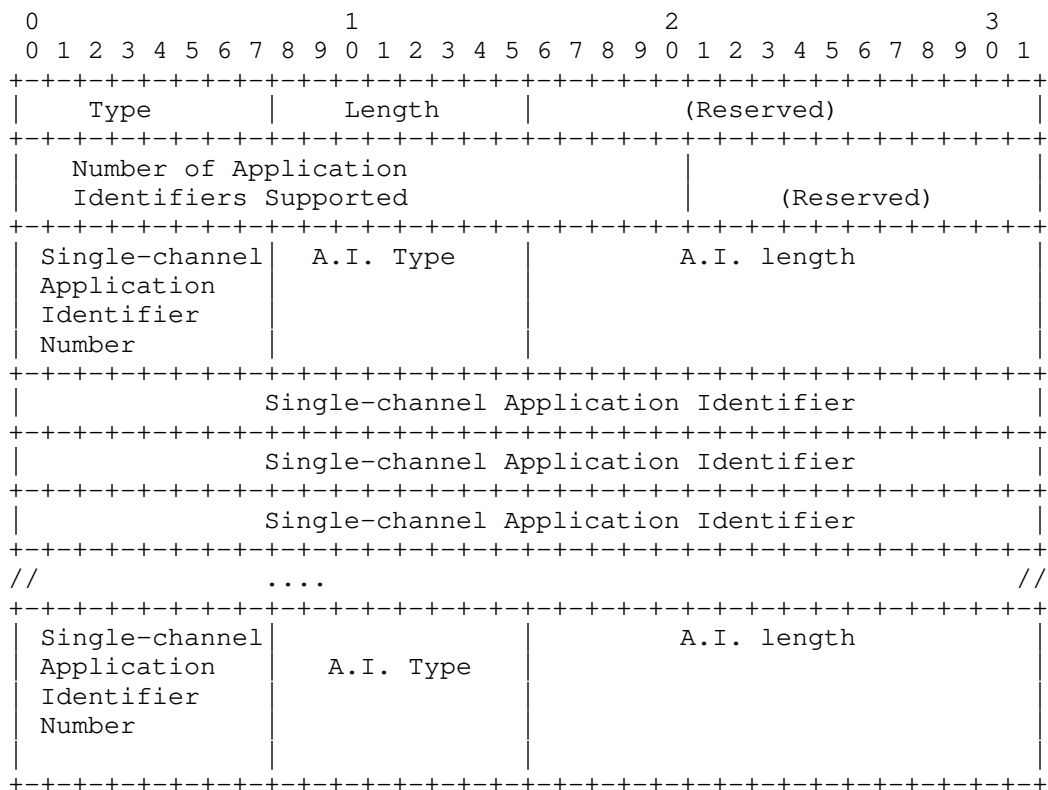
This message is to exchange the application identifiers supported as described in [G698.2]. There can be more than one Application Identifier supported by the transmitter/receiver in the OXC. The number of application identifiers supported is exchanged in the "OCh\_General" message. (from [G698.1]/[G698.2]/[G959.1] and G.874.1)



The parameters are

1. Number of Application Identifiers (A.I.) Supported
  2. Single-channel application identifier Number  
uniquely identifies this entry - 8 bits
  3. Application Identifier Type (A.I.) (STANDARD/PROPRIETARY)
  4. Single-channel application identifier -- 96 bits  
(from [G698.1]/[G698.2]/[G959.1])
- this parameter can have  
multiple instances as the transceiver can support multiple  
application identifiers.

Figure 4: The format of the this sub-object (Type = TBA, Length = TBA) is as follows:



```

|                               Single-channel Application Identifier                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Single-channel Application Identifier                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Single-channel Application Identifier                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

A.I. Type in use: STANDARD, PROPRIETARY

A.I. Type in use: STANDARD

Refer to G.698.2 recommendation : B-DScW-ytz(v)

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Single-channel Application Code                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Single-channel Application Code                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Single-channel Application Code                               |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

A.I. Type in use: PROPRIETARY

Note: if the A.I. type = PROPRIETARY, the first 6 Octets of the Application Identifier in use are six characters of the PrintableString must contain the Hexadecimal representation of an OUI (Organizationally Unique Identifier) assigned to the vendor whose implementation generated the Application Identifier; the remaining octets of the PrintableString are unspecified.

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               OUI                                                         |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               OUI cont. |                               Vendor value          |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Vendor Value                                                  |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

Figure 4: OCh\_ApplicationIdentifier

## 7. OCh\_Ss - OCh transmit parameters

These are the G.698.2 parameters at the Source(Ss reference points). Please refer to "draft-dharini-ccamp-dwdm-if-yang" for more details about these parameters.

### 1. Output power

Figure 5: The format of the OCh sub-object (Type = TBA, Length = TBA) is as follows:

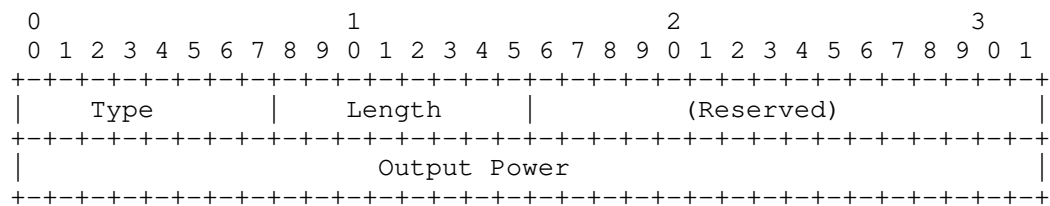


Figure 5: OCh\_Ss transmit parameters

## 8. OCh\_Rs - receive parameters

These are the G.698.2 parameters at the Sink (Rs reference points).

### 1. Current Input Power - (0.1dbm) 4bytes

Figure 6: The format of the OCh receive sub-object (Type = TBA, Length = TBA) is as follows:

The format of the OCh receive/OLS Sink sub-object (Type = TBA, Length = TBA) is as follows:

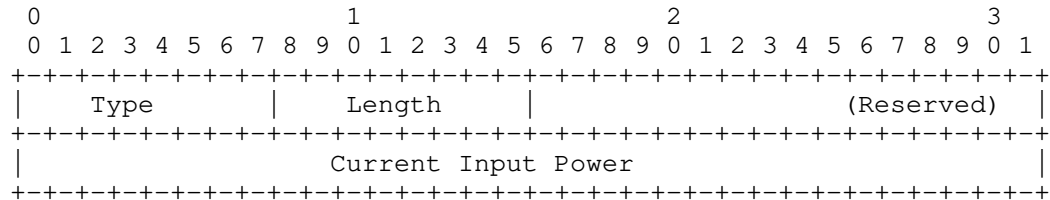


Figure 6: OCh\_Rs receive parameters

## 9. Security Considerations

LMP message security uses IPsec, as described in [RFC4204]. This document only defines new LMP objects that are carried in existing LMP messages, similar to the LMP objects in [RFC:4209]. This document does not introduce new security considerations.

## 10. IANA Considerations

LMP <xref target="RFC4204"/> defines the following name spaces and the ways in which IANA can make assignments to these namespaces:

- LMP Message Type
  - LMP Object Class
  - LMP Object Class type (C-Type) unique within the Object Class
  - LMP Sub-object Class type (Type) unique within the Object Class
- This memo introduces the following new assignments:

LMP Sub-Object Class names:

under DATA\_LINK Class name (as defined in <xref target="RFC4204"/>)

- OCh\_General (sub-object Type = TBA)
- OCh\_ApplicationIdentifier (sub-object Type = TBA)
- OCh\_Ss (sub-object Type = TBA)
- OCh\_Rs (sub-object Type = TBA)

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International Telecommunications Union, "Amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces", ITU-T Recommendation G.698.2, November 2009.

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A YANG model to manage the optical parameters for in a WDM network  
draft-galimbe-ccamp-iv-yang-03

## Abstract

This memo defines a Yang model that translate the information model to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functionality. The information model is defined in draft-ietf-ccamp-wson-iv-info and draft-martinelli-ccamp-wson-iv-encode. This document defines proper encoding and extend to the models defined in draft-lee-ccamp-wson-yang to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functions

The Yang model defined in this memo can be used for Optical Parameters monitoring and/or configuration of the multivendor Endpoints and ROADMs

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## 1. Introduction

This memo defines a Yang model that translates the existing mib module defined in draft-ietf-ccamp-wson-iv-info and draft-martinelli-ccamp-wson-iv-encode to provide the network impairment information to an SDN controller. One of the key SDN controller features is to support multi vendor network and support the service calculation and deployment in multilayer topologies, for the DWDM layer it is fundamental the SDN controller is aware of the optical impairments to verify the feasibility of new circuits before their provisioning. Although SDN controller will not apply exhaustive and accurate algorithms and the optical channel feasibility verification may have a degree of unreliability this function can work on a multivendor common set of parameter and algorithms to ensure the operator the best change to set a circuit. This document follows the same impairment definition and applicability of draft-ietf-ccamp-wson-iv-info.

For the optical impairments related to the DWDM Transceiver the draft draft-dharini-ccamp-if-param-yang. Applications are defined in G.698.2 [ITU.G698.2] using optical interface parameters at the single-channel connection points between optical transmitters and the optical multiplexer, as well as between optical receivers and the optical demultiplexer in the DWDM system. This Recommendation uses a methodology which explicitly specify the details of the optical network between reference point Ss and Rs, e.g., the passive and active elements or details of the design.

This draft refers and supports the draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

The building of a yang model describing the optical parameters allows the different vendors and operator to retrieve, provision and exchange information across multi-vendor domains in a standardized way. In addition to the parameters specified in ITU recommendations the Yang models support also the "vendor specific parameters".

## 2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

This memo specifies a Yang model for optical interfaces.

### 3. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. In the description of OIDs the convention: Set (S) Get (G) and Trap (T) conventions will describe the action allowed by the parameter.

### 4. Definition

For a detailed definition this draft refers to draft-ietf-ccamp-wson-iv-info.

### 5. Applicability

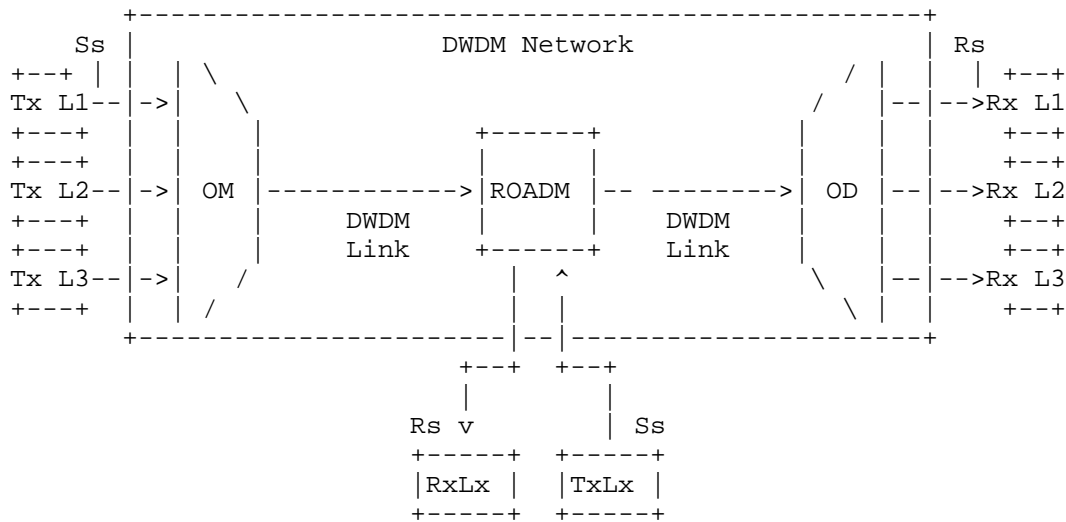
This document targets at Scenario C defined in [RFC6566] section 4.1.1. as approximate impairment estimation. The Approximate concept refers to the fact that this Information Model covers information mainly provided by [ITU.G680] Computational Model. Although the [RFC6566] provides no or little approximation the parameters described in this draft can be applied to the algorithms verifying the circuit feasibility in the new coherent non compensated DWDM networks. In this case the impairments verification can reach a good reliability and accuracy. This draft does not address computational matters but provides all the information suitable to cover most of the full coherent network algorithms, not being exhaustive the information can give a acceptable or even good approximation in terms of connection feasibility. This may not be true for legacy compensated network.

### 6. Properties

For the signal properties this draft refers to draft-ietf-ccamp-wson-iv-info Ch.2.3 with some extension of the parameters.

### 7. Overview

Figure 1 shows a set of reference points, for single-channel connection between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an OM and an OD (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more OADMs.



Ss = reference point at the DWDM network element tributary output  
Rs = reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: External transponder in WDM networks

## 7.1. Optical Parameters Description

The link between the external transponders through a WDM network media channels are managed at the edges, i.e. at the transmitters (Tx) and receivers (Rx) attached to the S and R reference points respectively. The set of parameters that could be managed are defined by the "application code" notation

The definitions of the optical parameters are provided below to increase the readability of the document, where the definition is

ended by (R) the parameter can be retrieve with a read, when (W) it can be provisioned by a write, (R,W) can be either read or written.

#### 7.1.1.1. Optical path from point Ss to Rs

The following parameters for the optical path from point S and R are defined in G.698.2 [ITU.G698.2].

##### Maximum and minimum (residual) chromatic dispersion:

These parameters define the maximum and minimum value of the optical path "end to end chromatic dispersion" (in ps/nm) that the system shall be able to tolerate. (R)

##### Minimum optical return loss at Ss:

These parameter defines minimum optical return loss (in dB) of the cable plant at the source reference point (Ss), including any connectors (R)

##### Maximum discrete reflectance between Ss and Rs:

Optical reflectance is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point. Control of reflections is discussed extensively in ITU-T Rec. G.957 (R)

##### Maximum differential group delay:

Differential group delay (DGD) is the time difference between the fractions of a pulse that are transmitted in the two principal states of polarization of an optical signal. For distances greater than several kilometres, and assuming random (strong) polarization mode coupling, DGD in a fibre can be statistically modelled as having a Maxwellian distribution. (R)

##### Maximum polarization dependent loss:

The polarization dependent loss (PDL) is the difference (in dB) between the maximum and minimum values of the channel insertion loss (or gain) of the black link from point SS to RS due to a variation of the state of polarization (SOP) over all SOPs. (R)

##### Maximum inter-channel crosstalk:

Inter-channel crosstalk is defined as the ratio of total power in all of the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths. The parameter specify the isolation of a link conforming to the "black link" approach such that under the worst-case operating conditions the inter-channel crosstalk at any reference point RS is less than the maximum inter-channel crosstalk value (R)

**Maximum interferometric crosstalk:**

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that under the worst case operating conditions the interferometric crosstalk at any reference point RS is less than the maximum interferometric crosstalk value. (R)

**Maximum optical path OSNR penalty:**

The optical path OSNR penalty is defined as the difference between the Lowest OSNR at Rs and Lowest OSNR at Ss that meets the BER requirement (R)

**Maximum ripple:**

Although is defined in G.698.2 (R).

**7.1.2. Rs and Ss Configuration**

For the Rs and Ss configuration this draft refers the draft-dharini-ccamp-dwdm-if-param-yang while for the Rs-Ss extended parameters for coherent transmission interfaces refer to draft-dharini-ccamp-dwdm-if-param-yang

**7.1.3. Table of Application Codes**

For Application Codes configuration this draft refers the draft-dharini-ccamp-dwdm-if-param-yang

**7.2. Use Cases**

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

**7.3. Optical Parameters for impairment validation in a WDM network**

The ietf-opt-parameters-wdm is an augment to the ?????. It allows the user to get and set the application Optical Parameters of a DWDM network.

```
module: ietf-opt-parameters-wdm
  +-rw gain-degrade-high?    dbm-t
  augment /if:interfaces/if:interface:
    +-rw optical-transport
      +-rw attenuator-value?   attenuator-t
      +-rw offset?            decimal64
      +-rw channel-power-ref?  decimal64
      +-rw tilt-calibration?   tilt-t
```

## 8. Structure of the Yang Module

ietf-opt-parameters-wdm is a top level model for the support of this feature.

## 9. Yang Module

The ietf-opt-parameters-wdm is defined as an extension to ietf interfaces ????.

<CODE BEGINS> file "ietf-opt-parameters-wdm.yang"

```
module ietf-opt-parameters-wdm {  
  namespace "urn:ietf:params:xml:ns:yang:ietf-opt-parameters-wdm";  
  prefix iietf-opt-parameters-wdm;
```

```
  import ietf-interfaces {  
    prefix if;  
  }
```

```
  import iana-if-type {  
    prefix ianaift;  
  }
```

```
  organization  
    "IETF CCAMP  
    Working Group";
```

```
  contact  
    "WG Web:  <http://tools.ietf.org/wg/ccamp/>  
    WG List:  <mailto:ccamp@ietf.org>
```

```
    Editor:    Gabriele Galimberti  
              <mailto:ggalimbe@cisco.com>";
```

```
  description  
    "This module contains a collection of YANG definitions for  
    collecting and configuring Optical Parameters  
    in Optical Networks and calculate the circuit feasibility.
```

```
    Copyright (c) 2016 IETF Trust and the persons identified  
    as authors of the code.  All rights reserved.
```



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```
revision "2016-10-30" {
    description
        "Initial revision.";
    reference
        "RFC XXXX: A YANG Data Model for Optical Parameters
        of DWDM Networks
        ";
}

typedef tilt-t {
    type decimal64 {
        fraction-digits 2;
        range "-5..5";
    }
    description "Tilt Type";
}

typedef signal-output-power-t {
    type decimal64 {
        fraction-digits 2;
        range "-10..30";
    }
    description "
        Amplifier Power provisioning ";
}

typedef active-channel-t {
    type union {
        type uint8 {
            range "0..200";
        }
    }
    description "
        Number of channels active on a span - and on an amplifier";
}

typedef dbm-t {
    type decimal64 {
```

```
        fraction-digits 2;
        range "-50..-30 | -10..5 | 10000000";
    }
    description "
        Amplifier Power in dBm ";
}

typedef attenuator-t {
    type decimal64 {
        fraction-digits 2;
        range "-15..-5";
    }
    description "
        Attenuation value (attenuator) applied after the Amplifier";
}

augment "/if:interfaces/if:interface" {
    when "if:type = 'ianaift:opticalTransport'" {
        description "Specific optical-transport Interface Data";
    }
    description "Specific optical-transport Interface Data";
    container optical-transport {
        description "Specific optical-transport Data";

        leaf attenuator-value {
            type attenuator-t;
            description "External attenuator value ";
        }

        leaf offset {
            type decimal64 {
                fraction-digits 2;
                range "-30..30";
            }
            description "Raman and power amplifiers offset";
        }

        leaf channel-power-ref {
            type decimal64 {
                fraction-digits 2;
                range "-10..15";
            }
            description "Optical power per channel";
        }

        leaf tilt-calibration {
            type tilt-t;
            description "Amplifier Tilt tuning";
        }
    }
}
```

```
    }  
  }  
}  
  
grouping opwr-threshold-warning-grp {  
  description "  
    Minimum Optical Power threshold  
    - this is used to rise Power alarm ";  
  
  leaf opwr-min {  
    type dbm-t;  
    units "dBm";  
    default -1;  
    description "Minimum Power Value";  
  }  
  
  leaf opwr-min-clear {  
    type dbm-t;  
    units "dBm";  
    default -1;  
    description "threshold to clear Minimum Power value Alarm";  
  }  
  
  leaf opwr-max {  
    type dbm-t;  
    units "dBm";  
    default 1;  
    description "  
      Maximum Optical Power threshold  
      - this is used to rise Power alarm ";  
  }  
}  
  
grouping gain-degrade-alarm-grp {  
  description "  
    Low Optical Power gain threshold  
    - this is used to rise Power alarm ";  
  
  leaf gain-degrade-low {  
    type dbm-t;  
    units "dBm";  
    default -1;  
    description "Low Gain Degrade Value";  
  }  
}  
  
leaf gain-degrade-high {  
  type dbm-t;
```

```
        units "dBm";
        default 1;
        description "
            High Optical Power gain threshold
            - this is used to rise Power alarm ";
    }
}

grouping power-degrade-high-alarm-grp {
    description "
        High Optical Power gain alarm ";

    leaf gain-degrade-high {
        type dbm-t;
        units "dBm";
        default 1;
        description "Low Gain Degrade Value";
    }
}

grouping power-degrade-low-alarm-grp {
    description "
        Low Optical Power gain alarm ";

    leaf power-degrade-low {
        type dbm-t;
        units "dBm";
        default -1;
        description "High Gain Degrade Value";
    }
}

grouping noise {
    leaf noise {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "Noise feasibility - reference ITU-T G.680
            OSNR added to the signal by the OMS. The noise is intended
            per channel and is independent of the number of active
            channels in OMS";
    }
    description "Noise feasibility";
}

grouping noise-sigma {
```

```
    leaf noise-sigma {
      type decimal64 {
        fraction-digits 2;
      }
      units "dB";
      description "Noise Sigma feasibility - accuracy of the
        OSNR added to
        the signal by the OMS";
    }
    description "Noise Sigma feasibility";
  }

  grouping chromatic-dispersion {
    leaf chromatic-dispersion {
      type decimal64 {
        fraction-digits 2;
      }
      units "ps/nm";
      description "Chromatic Dispersion (CD) related to the OMS";
    }
    description "Chromatic Dispersion (CD) feasibility";
  }

  grouping chromatic-dispersion-slope {
    leaf chromatic-dispersion-slope {
      type decimal64 {
        fraction-digits 2;
      }
      units "ps/nm^2";
      description "Chromatic Dispersion (CD) Slope related to
        the OMS";
    }
    description "Chromatic Dispersion (CD) Slope feasibility";
  }

  grouping pmd {
    leaf pmd {
      type decimal64 {
        fraction-digits 2;
      }
      units "ps";
      description "Polarization Mode Dispersion (PMD) related
        to OMS";
    }
    description "Polarization Mode Dispersion (PMD) feasibility";
  }

  grouping pdl {
```

```
    leaf pdl {
      type decimal64 {
        fraction-digits 2;
      }
      units "dB";
      description "Polarization Dependent Loss (PDL) related to
        the OMS";
    }
    description "Polarization Dependent Loss (PDL) feasibility";
  }

  grouping drop-power {
    leaf drop-power {
      type decimal64 {
        fraction-digits 2;
      }
      units "dBm";
      description "Drop Power value at the DWDM Transceiver RX
        side";
    }
    description "Drop Power feasibility";
  }

  grouping drop-power-sigma {
    leaf drop-power-sigma {
      type decimal64 {
        fraction-digits 2;
      }
      units "db";
      description "Drop Power Sigma value at the DWDM Transceiver
        RX side";
    }
    description "Drop Power Sigma feasibility";
  }

  grouping ripple {
    leaf ripple {
      type decimal64 {
        fraction-digits 2;
      }
      units "db";
      description "Channel Ripple";
    }
    description "Channel Ripple";
  }

  grouping ch-noise-figure {
    list ch-noise-figure {
```

```
    description "Channel signal-spontaneous noise figure";

    leaf input-to-output {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "from input port to output port";
    }

    leaf input-to-drop {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "from input port to drop port";
    }

    leaf add-to-output {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "from add port to output port";
    }
}
description "Channel signal-spontaneous noise figure";
}

grouping dgd {
    leaf dgd {
        type decimal64 {
            fraction-digits 2;
        }
        units "db";
        description "differential group delay";
    }
    description "differential group delay";
}

grouping ch-isolation {
    list ch-isolation {
        description "adjacent and not adjacent channel isolation";

        leaf ad-ch-isol {
            type decimal64 {
                fraction-digits 2;
            }
        }
    }
}
```





## 10. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operation and content.

## 11. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

URI: urn:ietf:params:xml:ns:yang:ietf-interfaces:ietf-ext-xponder-wdm-if

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC6020].

This document registers a YANG module in the YANG Module Names registry [RFC6020].

prefix: ietf-ext-xponder-wdm-if reference: RFC XXXX

## 12. Acknowledgements

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#### Appendix A. Change Log

This optional section should be removed before the internet draft is submitted to the IESG for publication as an RFC.

Note to RFC Editor: please remove this appendix before publication as an RFC.

#### Appendix B. Open Issues

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A YANG model to manage the optical parameters for in a WDM network  
draft-galimbe-ccamp-iv-yang-12

## Abstract

This memo defines a Yang model that translate the information model to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functionality. The information model is defined in draft-ietf-ccamp-wson-iv-info and draft-martinelli-ccamp-wson-iv-encode. This document defines proper encoding and extend to the models defined in draft-lee-ccamp-wson-yang to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functions

The Yang model defined in this memo can be used for Optical Parameters monitoring and/or configuration of the multivendor Endpoints and ROADMs. The use of this model does not guarantee interworking of transceivers over a DWDM. Optical path feasibility and interoperability has to be determined by means outside the scope of this document. The purpose of this model is to program interface parameters to consistently configure the mode of operation of transceivers.

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## 1. Introduction

This memo defines a Yang model that translates the existing mib module defined in draft-ietf-ccamp-wson-iv-info and draft-martinelli-ccamp-wson-iv-encode to provide the network impairment information to an SDN controller. One of the key SDN controller features is to support multivendor network and support the service calculation and deployment in multilayer topologies, for the DWDM layer it is fundamental that the SDN controller is aware of the optical impairments to verify the feasibility of new circuits before their provisioning. Although SDN controller will not apply exhaustive and accurate algorithms and the optical channel feasibility verification may have a degree of unreliability this function can work on a multivendor common set of parameter and algorithms to ensure the operator the best change to set a circuit. This document follows the same impairment definition and applicability of draft-ietf-ccamp-wson-iv-info.

The optical impairments related to the DWDM Transceiver are described by draft draft-dharini-ccamp-if-param-yang. Applications are defined in G.698.2 [ITU.G698.2] using optical interface parameters at the single-channel connection points between optical transmitters and the optical multiplexer, as well as between optical receivers and the optical demultiplexer in the DWDM system. This Recommendation uses a methodology which explicitly specify the details of the optical network between reference point Ss and Rs, e.g., the passive and active elements or details of the design.

The building of a yang model describing the optical parameters allows the different vendors and operator to retrieve, provision and exchange information across multi-vendor domains in a standardized way. In addition to the parameters specified in ITU recommendations the Yang models support also the "vendor specific parameters".

## 2. The Internet-Standard Management Framework

For a detailed overview of the documents that describe the current Internet-Standard Management Framework, please refer to section 7 of RFC 3410 [RFC3410].

This memo specifies a Yang model for optical interfaces.

### 3. Conventions

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC 2119 [RFC2119]. In the description of OIDs the convention: Set (S) Get (G) and Trap (T) conventions will describe the action allowed by the parameter.

### 4. Definition

For a detailed definition this draft refers to draft-ietf-ccamp-wson-iv-info.

### 5. Applicability

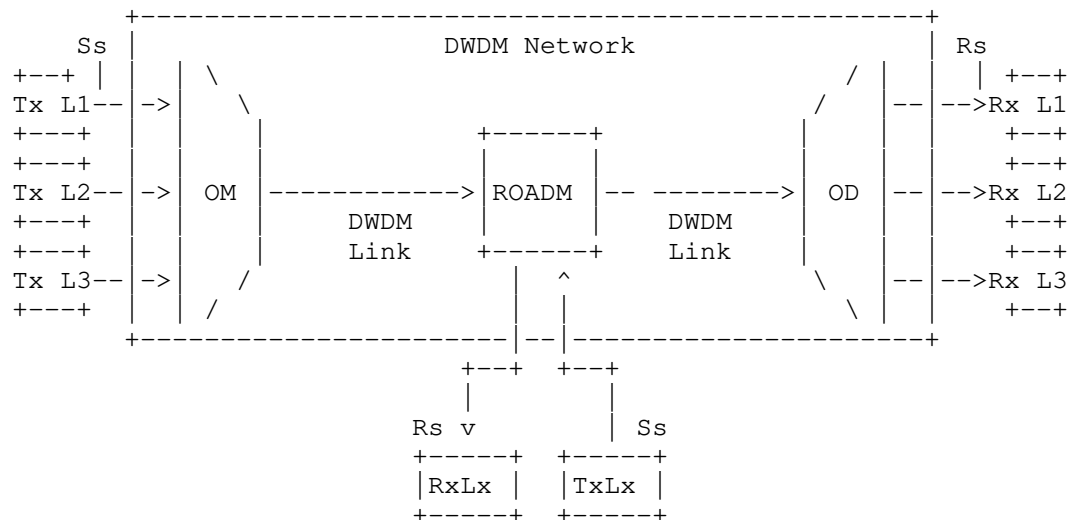
This document targets at Scenario C defined in [RFC6566] section 4.1.1. as approximate impairment estimation. The Approximate concept refers to the fact that this Information Model covers information mainly provided by [ITU.G680] Computational Model. Although the [RFC6566] provides no or little approximation the parameters described in this draft can be applied to the algorithms verifying the circuit feasibility in the new coherent non compensated DWDM networks. In this case the impairments verification can reach a good reliability and accuracy. This draft does not address computational matters but provides all the information suitable to cover most of the full coherent network algorithms, not being exhaustive the information can give an acceptable or even good approximation in terms of connection feasibility. This may not be true for legacy compensated networks.

### 6. Properties

For the signal properties this draft refers to draft-ietf-ccamp-wson-iv-info Ch.2.3 with some extension of the parameters.

### 7. Overview

Figure 1 shows a set of reference points, for single-channel connection between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an OM and an OD (which are used as a pair with the opposing element), one or more optical amplifiers and may also include one or more OADMs.



Ss = reference point at the DWDM network element tributary output

Rs = reference point at the DWDM network element tributary input

Lx = Lambda x

OM = Optical Mux

OD = Optical Demux

ROADM = Reconfigurable Optical Add Drop Mux

from Fig. 5.1/G.698.2

Figure 1: External transponder in WDM networks

### 7.1. Optical Parameters Description

The link between the external transponders through a WDM network media channels are managed at the edges, i.e. at the transmitters (Tx) and receivers (Rx) attached to the S and R reference points respectively. The set of parameters that could be managed are defined by the "application code" notation

The definitions of the optical parameters are provided below to increase the readability of the document, where the definition is

ended by (R) the parameter can be retrieve with a read, when (W) it can be provisioned by a write, (R,W) can be either read or written.

#### 7.1.1. Optical path from point Ss to Rs

The following parameters for the optical path from point S and R are defined in G.698.2 [ITU.G698.2].

Maximum and minimum (residual) chromatic dispersion:

These parameters define the maximum and minimum value of the optical path "end to end chromatic dispersion" (in ps/nm) that the system shall be able to tolerate. (R)

Minimum optical return loss at Ss:

These parameter defines minimum optical return loss (in dB) of the cable plant at the source reference point (Ss), including any connectors (R)

Maximum discrete reflectance between Ss and Rs:

Optical reflectance is defined to be the ratio of the reflected optical power present at a point, to the optical power incident to that point. Control of reflections is discussed extensively in ITU-T Rec. G.957 (R)

Maximum differential group delay:

Differential group delay (DGD) is the time difference between the fractions of a pulse that are transmitted in the two principal states of polarization of an optical signal. For distances greater than several kilometers, and assuming random (strong) polarization mode coupling, DGD in a fiber can be statistically modelled as having a Maxwellian distribution. (R)

Maximum polarization dependent loss:

The polarization dependent loss (PDL) is the difference (in dB) between the maximum and minimum values of the channel insertion loss (or gain) of the black link from point SS to RS due to a variation of the state of polarization (SOP) over all SOPs. (R)

Maximum inter-channel crosstalk:

Inter-channel crosstalk is defined as the ratio of total power in all of the disturbing channels to that in the wanted channel, where the wanted and disturbing channels are at different wavelengths. The parameter specifies the isolation of a link conforming to the "black link" approach such that under the worst-case operating conditions the inter-channel crosstalk at any reference point RS is less than the maximum inter-channel crosstalk value (R)

**Maximum interferometric crosstalk:**

This parameter places a requirement on the isolation of a link conforming to the "black link" approach such that under the worst case operating conditions the interferometric crosstalk at any reference point RS is less than the maximum interferometric crosstalk value. (R)

**Maximum optical path OSNR penalty:**

The optical path OSNR penalty is defined as the difference between the Lowest OSNR at Rs and Lowest OSNR at Ss that meets the BER requirement (R)

**Maximum ripple:**

Although is defined in G.698.2 (R).

**7.1.2. Rs and Ss Configuration**

For the Rs and Ss configuration this draft refers the draft-dharini-ccamp-dwdm-if-param-yang while for the Rs-Ss extended parameters for coherent transmission interfaces refer to draft-dharini-ccamp-dwdm-if-param-yang

**7.1.3. Table of Application Codes**

For Application Codes configuration this draft refers the draft-dharini-ccamp-dwdm-if-param-yang

**7.2. Use Cases**

The use cases are described in draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk

**7.3. Optical Parameters for impairment validation in a WDM network**

The ietf-opt-parameters-wdm is an augment to the ?????. It allows the user to get and set the application Optical Parameters of a DWDM network.

```
module: ietf-opt-parameters-wdm
  augment /if:interfaces/if:interface:
    +--rw optical-transport
    |   +--rw attenuator-value?      attenuator-t
    |   +--rw offset?                decimal64
    |   +--rw channel-power-ref?     decimal64
    |   +--rw tilt-calibration?      tilt-t
    +--rw opwr-threshold-warning
    |   +--rw opwr-min?              dbm-t
    |   +--rw opwr-min-clear?       dbm-t
```

```

|   +---rw opwr-max?          dbm-t
+---rw gain-degrade-alarm
|   +---rw gain-degrade-low?   dbm-t
|   +---rw gain-degrade-high?  dbm-t
+---rw power-degrade-high-alarm
|   +---rw gain-degrade-high?   dbm-t
+---rw power-degrade-low-alarm
|   +---ro power-degrade-low?   dbm-t
+---rw noise
|   +---rw noise?    decimal64
+---rw
|   +---rw noise?    decimal64
+---rw chromatic-dispersion
|   +---rw noise-sigma?    decimal64
+---rw chromatic-dispersion-slope
|   +---rw chromatic-dispersion-slope?    decimal64
+---rw pmd
|   +---rw pmd?    decimal64
+---rw pdl
|   +---rw pdl?    decimal64
+---rw drop-power
|   +---rw drop-power?    decimal64
+---rw drop-power-sigma
|   +---rw noise?    decimal64
+---rw ripple
|   +---rw drop-power-sigma?    decimal64
+---ro ch-noise-figure
|   +---ro ch-noise-figure* [ch-noise-fig]
|       +---ro ch-noise-fig          ch-noise-figure-point
|       +---ro input-to-output?    decimal64
|       +---ro input-to-drop?      decimal64
|       +---ro add-to-output?      decimal64
+---rw dgd
|   +---rw dgd?    decimal64
+---ro ch-isolation
|   +---ro ch-isolation* [ch-isolat]
|       +---ro ch-isolat          ch-isolation-cross
|       +---ro ad-ch-isol?      decimal64
|       +---ro no-ad-ch-iso?    decimal64
+---rw ch-extinction
|   +---rw cer?    decimal64

```

## 8. Structure of the Yang Module

ietf-opt-parameters-wdm is a top level model for the support of this feature.

## 9. Yang Module

The ietf-opt-parameters-wdm is defined as an extension to ietf interfaces ????.

<CODE BEGINS> file "ietf-opt-parameters-wdm.yang"

```
module ietf-opt-parameters-wdm {  
  namespace "urn:ietf:params:xml:ns:yang:ietf-opt-parameters-wdm";  
  prefix iietf-opt-parameters-wdm;
```

```
  import ietf-interfaces {  
    prefix if;  
  }
```

```
  import iana-if-type {  
    prefix ianaift;  
  }
```

```
  organization  
    "IETF CCAMP  
    Working Group";
```

```
  contact  
    "WG Web:   <http://tools.ietf.org/wg/ccamp/>  
    WG List:  <mailto:ccamp@ietf.org>
```

```
    Editor:   Gabriele Galimberti  
             <mailto:ggalimbe@cisco.com>;
```

```
  description  
    "This module contains a collection of YANG definitions for  
    collecting and configuring Optical Parameters  
    in Optical Networks and calculate the circuit feasibility.
```

```
    Copyright (c) 2016 IETF Trust and the persons identified  
    as authors of the code. All rights reserved.
```

```
    Redistribution and use in source and binary forms, with or  
    without modification, is permitted pursuant to, and  
    subject to the license terms contained in, the 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 "2021-06-28" {
    description
        "Revision 1.3";
    reference
        "";
}

revision "2020-03-13" {
    description
        "Revision 1.2";
    reference
        "";
}

revision "2018-10-22" {
    description
        "Revision 1.1";
    reference
        "";
}

revision "2018-03-06" {
    description
        "Revision 1.0";
    reference
        "";
}

revision "2016-10-30" {
    description
        "Initial revision.";
    reference
        "RFC XXXX: A YANG Data Model for Optical Parameters
        of DWDM Networks";
}

typedef tilt-t {
    type decimal64 {
        fraction-digits 2;
        range "-5..5";
    }
    description "Tilt Type";
}
```



```
}

typedef signal-output-power-t {
    type decimal64 {
        fraction-digits 2;
        range "-10..30";
    }
    description "
        Amplifier Power provisioning ";
}

typedef active-channel-t {
    type union {
        type uint8 {
            range "0..200";
        }
    }
    description "
        Number of channels active on a span - and on an amplifier";
}

typedef dbm-t {
    type decimal64 {
        fraction-digits 2;
        range "-50..-30 | -10..5 | 100000000";
    }
    description "
        Amplifier Power in dBm ";
}

typedef attenuator-t {
    type decimal64 {
        fraction-digits 2;
        range "-15..-5";
    }
    description "
        Attenuation value (attenuator) applied after the Amplifier";
}

typedef ch-noise-figure-point {
    type decimal64 {
        fraction-digits 2;
        range "-15..-5";
    }
    description "
        Amplifier noise figure of point power";
}
```

```
typedef ch-isolation-cross {
  type decimal64 {
    fraction-digits 2;
    range "-15..-5";
  }
  description "
cross channel isolation value";
}

grouping opwr-threshold-warning-grp {
  description "
    Minimum Optical Power threshold
    - this is used to rise Power alarm ";

  leaf opwr-min {
    type dbm-t;
    units "dBm";
    default -1;
    description "Minimum Power Value";
  }

  leaf opwr-min-clear {
    type dbm-t;
    units "dBm";
    default -1;
    description "threshold to clear Minimum Power value Alarm";
  }

  leaf opwr-max {
    type dbm-t;
    units "dBm";
    default 1;
    description "
      Maximum Optical Power threshold
      - this is used to rise Power alarm ";
  }
}

grouping gain-degrade-alarm-grp {
  description "
    Low Optical Power gain threshold
    - this is used to rise Power alarm ";

  leaf gain-degrade-low {
    type dbm-t;
    units "dBm";
    default -1;
    description "Low Gain Degrade Value";
  }
}
```

```
    }

    leaf gain-degrade-high {
      type dbm-t;
      units "dBm";
      default 1;
      description "
        High Optical Power gain threshold
        - this is used to rise Power alarm ";
    }
  }

  grouping power-degrade-high-alarm-grp {
    description "
      High Optical Power gain alarm ";

    leaf gain-degrade-high {
      type dbm-t;
      units "dBm";
      default 1;
      description "Low Gain Degrade Value";
    }
  }

  grouping power-degrade-low-alarm-grp {
    description "
      Low Optical Power gain alarm ";

    leaf power-degrade-low {
      type dbm-t;
      units "dBm";
      default -1;
      config false;
      description "High Gain Degrade Value";
    }
  }

  grouping noise-grp {
    description "Noise feasibility";
    leaf noise {
      type decimal64 {
        fraction-digits 2;
      }
      units "dB";
      description "Noise feasibility - reference ITU-T G.680
        OSNR added to the signal by the OMS. The noise is intended
        per channel and is independent of the number of active
```

```
        channels in OMS";
    }
}

grouping noise-sigma-grp {
    description "Noise sigma feasibility";
    leaf noise-sigma {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "Noise Sigma feasibility - accuracy of the
            OSNR added to
            the signal by the OMS";
    }
}

grouping chromatic-dispersion-grp {
    description "Chromatic Dispersion";
    leaf chromatic-dispersion {
        type decimal64 {
            fraction-digits 2;
        }
        units "ps/nm";
        description "Chromatic Dispersion (CD) related to the OMS";
    }
}

grouping chromatic-dispersion-slope-grp {
    description "Chromatic Dispersion slope";
    leaf chromatic-dispersion-slope {
        type decimal64 {
            fraction-digits 2;
        }
        units "ps/nm^2";
        description "Chromatic Dispersion (CD) Slope related to
            the OMS";
    }
}

grouping pmd-grp {
    description "Polarization Mode Dispersion";
    leaf pmd {
        type decimal64 {
            fraction-digits 2;
        }
        units "ps";
    }
}
```

```
        description "Polarization Mode Dispersion (PMD) related
            to OMS";
    }
}

grouping pdl-grp {
    description "Polarization Dependent Loss";
    leaf pdl {
        type decimal64 {
            fraction-digits 2;
        }
        units "dB";
        description "Polarization Dependent Loss (PDL) related to
            the OMS";
    }
}

grouping drop-power-grp {
    description "Drop power at DWDM if RX feasibility";
    leaf drop-power {
        type decimal64 {
            fraction-digits 2;
        }
        units "dBm";
        description "Drop Power value at the DWDM Transceiver RX
            side";
    }
}

grouping drop-power-sigma-grp {
    description "Drop power sigma at DWDM if RX feasibility ";
    leaf drop-power-sigma {
        type decimal64 {
            fraction-digits 2;
        }
        units "db";
        description "Drop Power Sigma value at the DWDM Transceiver
            RX side";
    }
}

grouping ripple-grp {
    description "Channel Ripple";
    leaf ripple {
        type decimal64 {
            fraction-digits 2;
        }
        units "db";
    }
}
```

```
        description "Channel Ripple";
    }
}

grouping ch-noise-figure-grp {
    list ch-noise-figure {
        key "ch-noise-fig";
        description "Channel signal-spontaneous noise figure";

        leaf ch-noise-fig {
            type ch-noise-figure-point;
            description "Channel signal-spontaneous noise
            figure point";
        }

        leaf input-to-output {
            type decimal64 {
                fraction-digits 2;
            }
            units "dB";
            description "from input port to output port";
        }

        leaf input-to-drop {
            type decimal64 {
                fraction-digits 2;
            }
            units "dB";
            description "from input port to drop port";
        }

        leaf add-to-output {
            type decimal64 {
                fraction-digits 2;
            }
            units "dB";
            description "from add port to output port";
        }
    }
    description "Channel signal-spontaneous noise figure";
}

grouping dgd-grp {
    description "Differential Group Delay";
    leaf dgd {
        type decimal64 {
            fraction-digits 2;
        }
    }
}
```

```
        units "db";
        description "differential group delay";
    }
}

grouping ch-isolation-grp {
    list ch-isolation {
        key "ch-isolat";
        description "adjacent and not adjacent channel isolation";

        leaf ch-isolat {
            type ch-isolation-cross;
            description "channel isolation from adjacent";
        }

        leaf ad-ch-isol {
            type decimal64 {
                fraction-digits 2;
            }
            units "dB";
            description "adjacent channel isolation";
        }

        leaf no-ad-ch-iso {
            type decimal64 {
                fraction-digits 2;
            }
            units "dB";
            description "non adjacent channel isolation";
        }
    }
    description "djacent and not adjacent channel isolation";
}

grouping ch-extinction-grp {
    description "Channel Extinsion";
    leaf cer {
        type decimal64 {
            fraction-digits 2;
        }
        units "db";
        description "channel extinction";
    }
}

grouping att-coefficient-grp {
    description "Attenuation coefficient (for a fibre segment)";
    leaf att {
```

```
    type decimal64 {
      fraction-digits 2;
    }
    units "db";
    description "Attenuation coefficient (for a fibre segment)";
  }
}

augment "/if:interfaces/if:interface" {
  when "if:type = 'ianaift:opticalTransport'" {
    description "Specific optical-transport Interface Data";
  }
  description "Specific optical-transport Interface Data";
  container optical-transport {
    description "Specific optical-transport Data";

    leaf attenuator-value {
      type attenuator-t;
      description "External attenuator value ";
    }

    leaf offset {
      type decimal64 {
        fraction-digits 2;
        range "-30..30";
      }
      description "Raman and power amplifiers offset";
    }

    leaf channel-power-ref {
      type decimal64 {
        fraction-digits 2;
        range "-10..15";
      }
      description "Optical power per channel";
    }

    leaf tilt-calibration {
      type tilt-t;
      description "Amplifier Tilt tuning";
    }
  }
  container opwr-threshold-warning {
    description "Optical power threshold warning";
    uses opwr-threshold-warning-grp;
  }
  container gain-degrade-alarm {
```



```
        description "Gain degrade alarm";
        uses gain-degrade-alarm-grp;
    }
    container power-degrade-high-alarm {
        description "Power degrade high aparm";
        uses power-degrade-high-alarm-grp;
    }
    container power-degrade-low-alarm {
        description "Power degrade low alarm";
        uses power-degrade-low-alarm-grp;
    }
    container noise {
        description "Channel Noise feasibility";
        uses noise-grp;
    }
    container noise-sigma {
        description "Channel Noise sigma feasibility";
        uses noise-grp;
    }
    container chromatic-dispersion {
        description "Chromatic Dispersion";
        uses noise-sigma-grp;
    }
    container chromatic-dispersion-slope {
        description "Chromatic Dispersion slope";
        uses chromatic-dispersion-slope-grp;
    }
    container pmd {
        description "Polarization Mode Dispersion";
        uses pmd-grp;
    }
    container pdl {
        description "Polarization Dependent Loss";
        uses pdl-grp;
    }
    container drop-power {
        description "Drop power at DWDM if RX feasibility";
        uses drop-power-grp;
    }
    container drop-power-sigma {
        description "Drop power sigma at DWDM if RX feasibility";
        uses noise-grp;
    }
    container ripple {
        description "Channel Ripple";
        uses drop-power-sigma-grp;
    }
    container ch-noise-figure {
```

```
        config false;
        description "Channel signal-spontaneous noise figure";
        uses ch-noise-figure-grp;
    }
    container dgd {
        description "Differential Group Delay";
        uses dgd-grp;
    }
    container ch-isolation {
        config false;
        description "adjacent and not adjacent channel isolation";
        uses ch-isolation-grp;
    }
    container ch-extinction {
        description "Channel Extinsion";
        uses ch-extinction-grp;
    }
}
}
}
```

<CODE ENDS>

## 10. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operation and content.

## 11. IANA Considerations

This document registers a URI in the IETF XML registry [RFC3688]. Following the format in [RFC3688], the following registration is requested to be made:

URI: urn:ietf:params:xml:ns:yang:ietf-interfaces:ietf-ext-xponder-wdm-if

Registrant Contact: The IESG.

XML: N/A, the requested URI is an XML namespace.

This document registers a YANG module in the YANG Module Names registry [RFC6020].

This document registers a YANG module in the YANG Module Names registry [RFC6020].

prefix: ietf-ext-xponder-wdm-if reference: RFC XXXX

## 12. Acknowledgements

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#### Appendix A. Change Log

This optional section should be removed before the internet draft is submitted to the IESG for publication as an RFC.

Note to RFC Editor: please remove this appendix before publication as an RFC.

#### Appendix B. Open Issues

Note to RFC Editor: please remove this appendix before publication as an RFC.

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Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense  
Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage  
the application code of optical interface parameters in DWDM application  
draft-ggalimbe-ccamp-flex-if-lmp-02

#### Abstract

This experimental memo defines extensions to LMP(rfc4209) for  
managing Optical parameters associated with Wavelength Division  
Multiplexing (WDM) adding a set of parameters related to multicarrier  
DWDM interfaces to be used in Spectrum Switched Optical Networks  
(sson).

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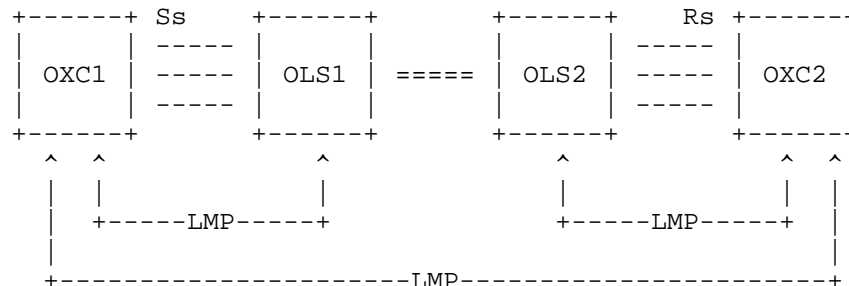
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## 1. Introduction

This experimental extension addresses the use cases described by "draft-kdkgall-ccamp-dwdm-if-mng-ctrl-fwk-00" to the Spectrum Switched Optical Network applications. LMP [RFC4902] provides link property correlation capabilities that can be used between a transceiver device and an Optical Line System (OLS) device. Link property correlation is a procedure by which, intrinsic parameters and capabilities are exchanged between two ends of a link. Link property correlation as defined in RFC3591 allows either end of the link to supervise the received signal and operate within a commonly understood parameter window. Here the term 'link' refers in particular to the attachment link between OXC and OLS (see Figure 1). The relevant novelty is the interface configuration having a multiple carrier where the client signal is spread on. The parameters parameters are not yet fully defined by ITU-T so this document can just be seen as an experimental proposal not binding operators and vendors to require and implement them



Figure 2 Extended LMP Model ( from [RFC4209] )



OXC : is an entity that contains Multiple carriers transponders  
 OLS : generic Flex-Spectrum optical system, it can be -  
       Optical Mux, Optical Demux, Optical Add  
       Drop Mux, Amplifier etc.  
 OLS to OLS: represents the Optical Multiplex section  
       <xref target="ITU.G709"/>  
 Rs/Ss : reference points in between the OXC and the OLS

Figure 2: Extended LMP Model

### 3. Use Cases

The set of parameters exchanged between is to support the Spectrum Switched Optical Network in terms of Number of Sub-carriers available at the transceiver, their characteristics to provide the SSON control plane all the information suitable to calculate the

### 4. Extensions to LMP-WDM Protocol

This document defines extensions to [RFC4209] to allow a set of characteristic parameters, to be exchanged between a router or optical switch and the optical line system to which it is attached. In particular, this document defines additional Data Link sub-objects to be carried in the LinkSummary message defined in [RFC4204] and [RFC6205]. The OXC and OLS systems may be managed by different Network management systems and hence may not know the capability and status of their peer. These messages and their usage are defined in subsequent sections of this document.

The following new messages are defined for the SSON extension

- Multi carrier Transceiver (sub-object Type = TBA)

## 5. Multi carrier Transceiver

These are a set of general parameters extending the description in [G698.2] and [G.694.1]. IYU-T working group are working to detail most of parameters and an update of the TLV may be required.

The general parameters are

1. Modulation identifier: indicates the Transceiver capabilities to support a single or multiple modulation format like:  
BPSK (1), DC-DP-BSPSK, QPSK, DP-QPSK, QAM16, DP-QAM16, DC-DP-QAM16
2. FEC: indicates the FEC types the transceiver can support
3. baud rate: number of symbols rate, basically this identify the channel frequency
4. Num Carriers: number of subcarriers the trasceiver can support and can be "mapped" in a Mediachannel
5. Bits/symbol: number of bit per simbol (aka spectral efficiency)
6. Subcarrier band (minimum distance between subcarriers) in GHz
7. Guard band (required guard band at the side of media channel)
8. Sub-carrier TX Power: output optical power the transceiver can provide
9. Sub-carrier RX Power: Input optical power Range the transceiver can support, this is known also as Sensitivity
10. Sub-carrier OSNR robustness

Figure 3: The format of the this sub-object (Type = TBA, Length = TBA) is as follows:

0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1								
Type										Length										(Reserved)																			
S I		Modulation ID										FEC																											
baud rate										(Symbol Rate)																													
Number of subcarriers										Bit/Symbol																													
subcarrier band										guard band																													
sub-carrier TX power																																							
sub-carrier RX power HIGH																																							
sub-carrier RX power LOW																																							
sub-carrier OSNR																																							

- S: standardized format;
- I: input / output (1 / 0)
- Modulation IDs: BPSK (1), DC DP BPSK, QPSK, DP QPSK, 8QAM  
16QAM, 64QAM
- FEC
- baud rate: Symbol Rate IEEE float in bauds/s
- Num Carriers
- Bits/symbol
- Subcarrier band (minimum distance between subcarriers)
- Guard band (required guard band at the side of media channel)
- Sub-carrier Transmit Power
- Sub-carrier Receive HIGH Power range (Sensitivity)
- Sub-carrier Receive LOW Power range (Sensitivity)
- Sub-carrier OSNR robustness

Figure 3: Multi carrier Transceiver

## 6. Security Considerations

LMP message security uses IPsec, as described in [RFC4204]. This document only defines new LMP objects that are carried in existing

LMP messages, similar to the LMP objects in [RFC:4209]. This document does not introduce new security considerations.

## 7. IANA Considerations

LMP <xref target="RFC4204"/> defines the following name spaces and the ways in which IANA can make assignments to these namespaces:

- LMP Message Type
  - LMP Object Class
  - LMP Object Class type (C-Type) unique within the Object Class
  - LMP Sub-object Class type (Type) unique within the Object Class
- This memo introduces the following new assignments:

LMP Sub-Object Class names:

under DATA\_LINK Class name (as defined in <xref target="RFC4204"/>)

- Multi carrier Transceiver (sub-object Type = TBA)

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Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense  
Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage  
the application code of optical interface parameters in DWDM application  
draft-ggalimbe-ccamp-flex-if-lmp-13

#### Abstract

This experimental memo defines extensions to LMP(rfc4209) for  
managing Optical parameters associated with Wavelength Division  
Multiplexing (WDM) adding a set of parameters related to multicarrier  
DWDM interfaces to be used in Spectrum Switched Optical Networks  
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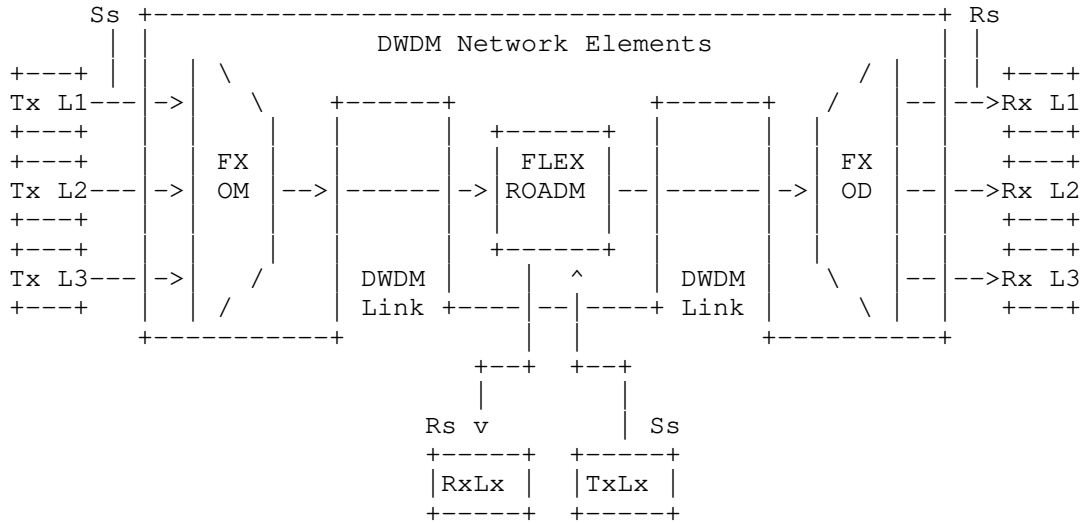
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## 1. Introduction

This experimental extension addresses the use cases described by "draft-ietf-ccamp-dwdm-if-lmp" and extends it to the Spectrum Switched Optical Network applications. LMP [RFC4902] provides link property correlation capabilities that can be used between a transceiver device and an Optical Line System (OLS) device. Link property correlation is a procedure by which, intrinsic parameters and capabilities are exchanged between two ends of a link. Link property correlation as defined in RFC4204 allows either end of the link to supervise the received signal and operates within a commonly understood parameter window. Here the term 'link' refers in particular to the attachment link between OXC and OLS (see Figure 1). The relevant novelty is the interface configuration having a multiple carrier where the client signal is spread on. The parameters are not yet fully defined by ITU-T, so this document can just be seen as an experimental proposal not binding operators and vendors to comply and implement them

## 2. DWDM line system

Figure 1 shows a set of reference points (Rs and Ss), for a single-channel connection between transmitter (Tx) and receiver (Rx) devices. Here the DWDM network elements in between those devices include an Optical Multiplexer (OM) and an Optical Demultiplexer (OD). In addition it may include one or more Optical Amplifiers (OA) and one or more Optical Add-Drop Multiplexers (OADM).



Ss = Sender reference point at the DWDM network element tributary output, this can be a set of multiple transceivers carrying the same client payload.

Rs = Receiver reference point at the DWDM network element tributary input this can be a set of multiple transceivers carrying the same client payload.

FX OM = Flex-Spectrum Optical Mux

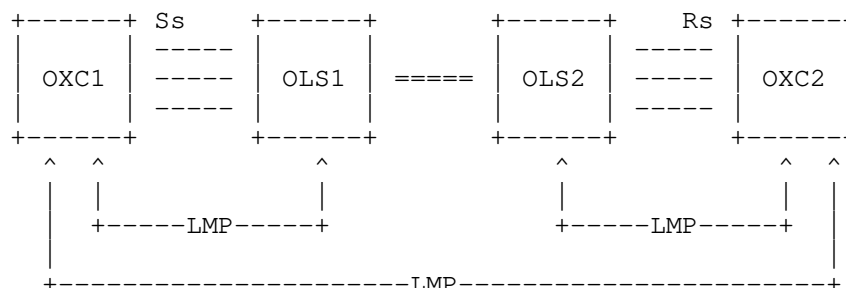
FX OD = Flex-Spectrum Optical Demux

Flex ROADM = Flex-Spectrum Optical Add Drop Mux (reconfigurable)

extending Fig. 5.1/G.698.2

Figure 1: Linear Single Channel approach

Figure 2 Extended LMP Model ( from [RFC4209] )



OXC : is an entity that contains Multiple carriers transponders  
 OLS : generic Flex-Spectrum optical system, it can be -  
       Optical Mux, Optical Demux, Optical Add  
       Drop Mux, Amplifier etc.  
 OLS to OLS: represents the Optical Multiplex section  
       <xref target="ITU.G709"/>  
 Rs/Ss : reference points in between the OXC and the OLS

Figure 2: Extended LMP Model

### 3. Use Cases

The set of parameters exchanged between OXC and OLS is to support the Spectrum Switched Optical Network in terms of Number of Sub-carriers available at the transceiver and their characteristics to provide the SSON control plane all the information suitable to calculate the path and the optical feasibility. This draft extends the "draft-ietf-ccamp-dwdm-if-lmp" to sson applications.

### 4. Extensions to LMP-WDM Protocol

This document defines extensions to [RFC4209] to allow a set of characteristic parameters, to be exchanged between a router or optical switch and the optical line system to which it is attached. In particular, this document defines additional Data Link sub-objects to be carried in the LinkSummary message defined in [RFC4204] and [RFC6205]. The OXC and OLS systems may be managed by different Network Management Systems and hence may not know the capability and status of their peer. These messages and their usage are defined in subsequent sections of this document.

The following new messages are defined for the SSON extension

- Multi carrier Transceiver (sub-object Type = TBA)

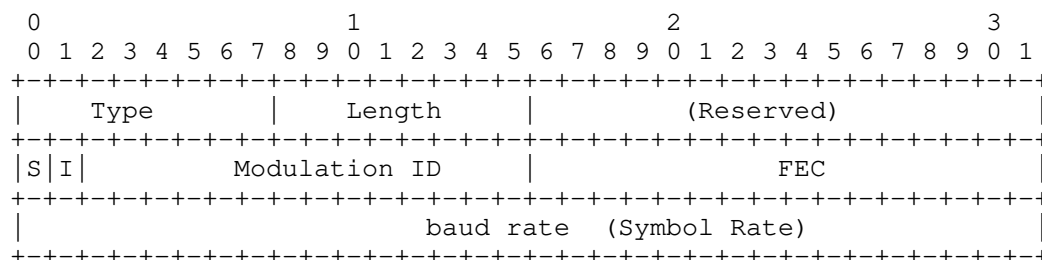
## 5. Multi carrier Transceiver

These are a set of general parameters extending the description in [G698.2] and [G.694.1]. ITU-T working groups are working to detail most of parameters and an update of the TLV may be required.

Other than the Application Identifier described in [G698.2] and draft-ietf-ccamp-dwdm-if-lmp the parameters to describe a multicarrier transceiver are describes as follows:

1. Modulation format: indicates the Transceiver capabilities to support a single or multiple modulation format like: BPSK, DC-DP-BSPSK, QPSK, DP-QPSK, QAM16, DP-QAM16, DC-DP-QAM16, 64QAM. Hybrid modulation format are supported as well and the parameter is given in bit per symbol.
2. FEC: indicates the FEC types the transceiver can support
3. baud rate: symbols rate, basically this identify the channel symbols number per second
4. Num Carriers: number of (sub)carriers the trasceiver can support and can be "mapped" in a Mediachannel (or tunnel)
5. Bits/symbol: number of bit per simbol - fractional in case of hybrid modulation format. (aka spectral efficiency)
6. Subcarrier band (minimum distance between subcarriers) in GHz
7. Guard band (required guard band at the side of media channel)
8. Sub-carrier TX Power: output optical power the transceiver can provide
9. Sub-carrier RX Power: Input optical power Range the transceiver can support, this is known also as Sensitivity
- 10 Max-pol-power-difference: max power difference between the polarised components
- 11 Max-pol-skew-difference: maw Skew between polarised signal and subcarriers supported by the transceiver
12. Max-inter-carrier-skew: maximum skew between carriers in the same mediachannel (or tunnel)
13. Sub-carrier OSNR robustness

Figure 3: The format of the this sub-object (Type = TBA, Length = TBA) is as follows:



Number of subcarriers	Bit/Symbol
subcarrier band	guard band
sub-carrier TX power	
sub-carrier RX power HIGH	
sub-carrier RX power LOW	
Max-pol-power-difference	
Max-pol-skew-difference	
Max-inter-carrier-skew	
sub-carrier OSNR	

- S: standardized format;
- I: input / output (1 / 0)
- Modulation ID (Format) : is the modulation type:  
BPSK, DC DP BPSK, QPSK, DP QPSK, 8QAM, 16QAM, 32QAM, 64QAM, etc.
  - <TBD> (ITU-T reference)
  - value > 32768 (first bit is 1): custom defined values
 Value 0 is reserved to be used if no value is defined
- FEC: the signal Forward Error Corrections type (16-bit unsigned integer), the defined values are:
  - <TBD> (ITU-T reference)
  - 32768 (first bit is 1): custom defined values
 Value 0 is reserved to be used if no value is defined
- Baud Rate: the signal symbol rate (IEEE 32-bit float, in bauds/s)  
Value 0 is reserved to be used if no value is defined
- Num Carriers
- Bits/symbol(BPS) this indicates the bit per symbol in case of hybrid modulation format. It is an off-set with values from 0 to 127 to be applied to the specified Modulation Format and indicates the mix between the selected Modulation Format and its upper adjacent.  
(e.g. QPSK + 63 BPS indicates that there is a 50% MIX between QPSK and 8-QAM = 2.5 bits per symbol) If value = 0 the standard Modulation Format is applied
- Subcarrier band (minimum distance between subcarriers)
- Guard band (required guard band at the side of media channel)
- Sub-carrier Transmit Power
- Sub-carrier Receive HIGH Power range (Sensitivity)

- Sub-carrier Receive LOW Power range (Sensitivity)
- Sub-carrier OSNR robustness
- Max-pol-power-difference
- Max-pol-skew-difference
- Max-inter-carrier-skew
- Sub-carrier OSNR

Figure 3: Multi carrier Transceiver

## 6. Security Considerations

LMP message security uses IPsec, as described in [RFC4204]. This document only defines new LMP objects that are carried in existing LMP messages, similar to the LMP objects in [RFC:4209]. This document does not introduce new security considerations.

## 7. IANA Considerations

LMP <xref target="RFC4204"/> defines the following name spaces and the ways in which IANA can make assignments to these namespaces:

- LMP Message Type
  - LMP Object Class
  - LMP Object Class type (C-Type) unique within the Object Class
  - LMP Sub-object Class type (Type) unique within the Object Class
- This memo introduces the following new assignments:

LMP Sub-Object Class names:

under DATA\_LINK Class name (as defined in <xref target="RFC4204"/>)

- Multi carrier Transceiver (sub-object Type = TBA)

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Signaling extensions for Media Channel sub-carriers configuration in  
Spectrum Switched Optical Networks (SSON) in Lambda Switch Capable (LSC)  
Optical Line Systems.  
draft-ggalimbe-ccamp-flexigrid-carrier-label-12

#### Abstract

This memo defines the signaling extensions for managing Spectrum Switched Optical Network (SSON) parameters shared between the Client and the Network and inside the Network in accordance to the model described in [RFC7698]. The extensions are in accordance and extending the parameters defined in ITU-T Recommendation G.694.1.[ITU.G694.1] and its extensions and G.872.[ITU.G872].

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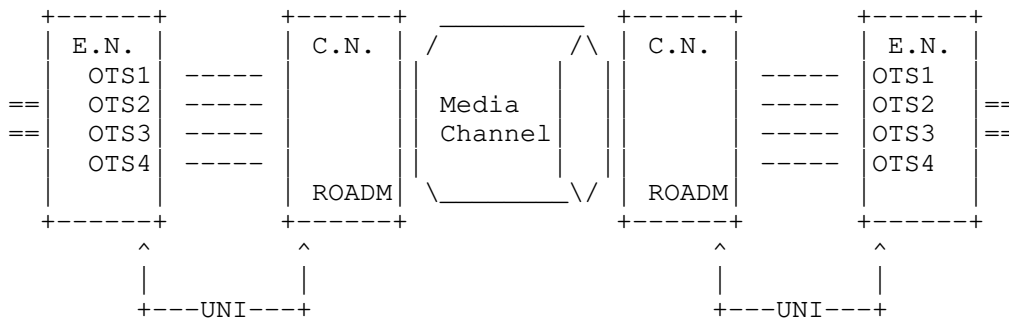
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## 1. Introduction

Generalized Multiprotocol Label Switching (GMPLS) is widely used in Wavelength Switched Optical Network (WSO) to support the optical circuit set-up through the signalling between Core Nodes and Edge Nodes (reusing terminology from [RFC4208]). This extension addresses the use cases described by [RFC7698] Ch.3.3 and supports the information, needed in Spectrum Switched Optical Network (SSON), to signal a Media Channel and the associated carriers set request. The new set of parameters is related to the Media Channel and the carrier(s) routed with it and keep the backward compatibility with the WSO signalling. In particular this memo addresses the use cases where the SSON LSP (the Media Channel in RFC7698) use multiple

carrier (OTSi) to carry the Payload. The set of the carriers can be seen as single Logical circuit. This memo can be considered as the extension of [RFC7792].

Figure 1 shows how the multiple carrier are mapped into a Media Channel. A set of parameters must be shared on the UNI to allow the core control plane to do the proper routing and Spectrum Assignment and decide the carrier position.



E.N. = Edge Node (a.k.a. UNI Client / transceiver shelf)  
 C.N. = Core Node (a.k.a. UNI Network / edge ROADM)  
 ROADM = Lambda/Spectrum switch  
 Media Channel = the optical circuit  
 OTSi = Carriers belonging to the same Network Media Channel (or Super Channel or OTSiG)  
 UNI = Signalling interface between E.N. and C.N.

Figure 1: Multi carrier LSP

## 2. Client interface parameters

The Edge Node interface can have one or multiple carriers (OTSi). All the carrier have the same characteristics and are provisionable in terms of:

### Number of subcarriers:

This parameter indicates the number of subcarriers (OTSi) available for the super-channel (OTSiG or OTSiA) in case the Transceiver can support multiple carrier circuits. The OTSi is defined in ITU-T Recommendation G.959.1, section 3.2.4 [G.959.1]. 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]. This draft specifies the case where the each carrier (OTSi) is terminated on a physical port so the transceiver can have multiple ports. In future editions also the case where multiple carriers are terminated on the same port will be supported (also known as Sliceable Transponders).

Central frequency (see G.694.1 Table 1):

This parameter indicates the Central frequency value that Ss and Rs will be set to work (in THz). See the details in Section 6/ G.694.1 or based on "n" value explanation and the following "k" values definition in case of multicarrier transceivers.

Central frequency granularity:

This parameter indicates the Central frequency granularity supported by the transceiver, this value is combined with k and n value to calculate the central frequency of the carrier or sub-carriers.

Minimum channel spacing:

This is the minimum nominal difference in frequency (in GHz) between two adjacent channels (or carriers) depending on the Transceiver characteristics and provisioning.

Bit rate / Baud rate of Optical Tributary Signals (OTSi):

Optical Tributary Signal bit (for NRZ signals) rate or Symbol (for Multiple bit per symbol) rate .

FEC Coding:

This parameter indicate what Forward Error Correction (FEC) code is used at Ss and Rs (R/W) (not mentioned in G.698.2). .

Wavelength Range (see G.694.1): [ITU.G694.1]

This parameter indicate minimum and maximum wavelength spectrum in a definite wavelength Band (L, C and S). That is the transceiver tunability range

Modulation format:

This parameter indicates the list of supported Modulation Formats and the provisioned Modulation Format.

Inter carrier skew:

This parameter indicates, in case of multi-carrier LSP (OTSiG) the maximum skew between the sub-carriers OTSi) supported by the transceivers.

Laser Output power:

This parameter provisions the Transceiver Output power, it can be either a setting and measured value.

Receiver input power:

This parameter provisions the Min and Max input power supported by the Transceiver, i.e. Receiver Sensitivity.

The above parameters are related to the Edge Node Transceiver and are used by the Core Network control plane in order to calculate the optical feasibility and the spectrum allocation. The parameters can be shared between the Client and the Network via LMP or provisioned to the Network by an EMS or an operator OSS.

### 3. Use Cases

The use cases are described in [RFC7698]

### 4. Signalling Extensions

The following sections specify the fields used in the RSVP-TE Path and Resv messages to address the requirements above. The above parameters could be applied to [RFC4208] scenarios but they are valid also in case of non UNI scenarios. The [RFC7699] parameters remain valid.

#### 4.1. New LSP Request Parameters

When the E.N. wants to request to the C.N. a new circuit set-up, i.e. the control plane wants to signal in the SSON network the Optical Interface characteristics, the following parameters will be provided to the C.N.:

Number of available subcarriers (c):

This parameter is an integer and identifies the number of OTSi in an OTSiG. In this version of the document, it maps to the number of Client ports connected to the Core ports available to support the requested circuit.

Total bandwidth request:

e.g. 200Gb, 400Gb, 1Tb - it is the bandwidth (payload) to be carried by the multiple carrier circuit (OTSiG). In alternative the OTUCn can be used

Policy (strict/loose):

Strict/loose referred to B/W and subcarrier number. This is to give some flexibility to the GMPLS in order to commit client request.



Subcarrier bandwidth tunability:  
(optional) e.g. 34Ghz, 48GHz.

The TLV define the resource constraints for the requested Media Channel.

The format of the sub-object is as follows:

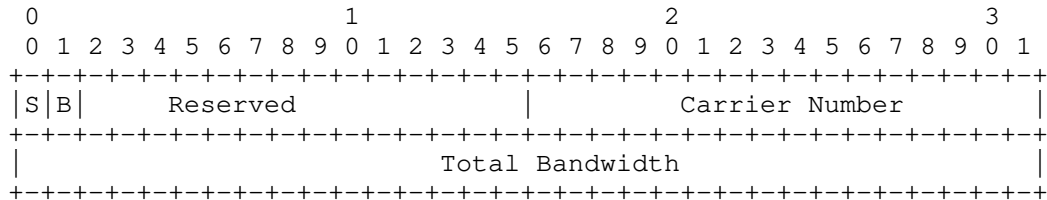


Figure 2: SSON LSP set-up request

Carrier Number: number of carrier to be allocated for the requested channel (16-bit unsigned integer)  
If Carrier Number == 0 no constraint set on the number of carriers to be used

Total Bandwidth: the requested total bandwidth to be supported by the Media Channel (32-bit IEEE float, bytes/s)  
If Total Bandwidth == 0: no bandwidth constraint is defined (B must be 0)

S strict number of subcarrier

- S = 0: the number of requested carriers is the maximum number that can be allocated (a lower value can be allocated if the requested bandwidth is satisfied)
- S = 1: the number of requested carriers is strict (must be > 0)

B Bandwidth constraints

- B = 0: the value is the maximum requested bandwidth (a lower value can be allocated if resources are not available)
- B = 1: the requested bandwidth is the minimum value to be allocated (a higher value can be allocated if requested by the physical constraints of the ports)

Reserved: unused bit (for future use, should be 0)

Note: bandwidth unit is defined in accordance to RFC 3471 chap. 3.1.2 Bandwidth Encoding specification. Bandwidth higher than 40Gb/s values must be defined (e.g. 100Gb/s, 150Gb/s 400Gb/s, etc.) or in alternative the OTUCn defined in ITU-T G.709.

TLV Usage in RSVP-TE message:

Path from head E.N.: requested traffic constraints, the Head C.N. must satisfy when reserving the optical resources and defining the carriers configuration

The TLV can be omitted: no traffic constraints is defined (resources allocated by C.N. based on a local policy)

#### 4.2. Extension to LSP set-up specification

Once the WDM control plane (running in C.N.) has calculated the Media Channel path, the Spectrum Allocation, the Sub-carrier number and frequency, the modulation format, the FEC and the Transmit power, the path set-up confirmation MUST be sent back to the E.N. providing the values of the calculated parameters:

Media Channel:

(Grid, C.S., Identifier m and n). as indicated in RFC7699 Section 4.1

Modulation format:

This parameter indicates the Modulation Formats to be set in the Transceivers.

FEC Coding:

This parameter indicate what Forward Error Correction (FEC) code must be used by the Transceivers (not mentioned in G.698). .

Baud rate of optical tributary signals:

Symbol (for Multiple bit per symbol) rate.

List of subcarriers:

This parameter indicates the subcarriers to be used for the super-channel (OTSiG) in case the Transceiver can support multiple carrier Circuits.

Carriers Central frequency granularity (J):

This parameter indicates the Central frequency granularity supported by the transceiver, this value is combined with K and n value to calculate the central frequency on the carrier or sub-carriers.

Carrier Central frequency (see G.694.1 Table 1) (k):

Grid, Identifiers, central frequency and granularity.

Laser Output power:

This parameter provisions the Transceiver Output power, it can be either a setting and measured value.

Circuit Path, RRO, etc:

All these info are defined in [RFC4208].

Path Error:

e.g. no path exist, all the path error defined in [RFC4208].

#### 4.2.1. Common Signal Description TLV

The TLV defines the carriers signal configuration.

All carriers in a Media Channel MUST have the same configuration.

It is aligned with TLV in 3.2.1 section in

[I-D.draft-meuric-ccamp-tsvmode-signaling].

The format of this sub-object (Type = TBA, Length = TBA) is as follows:

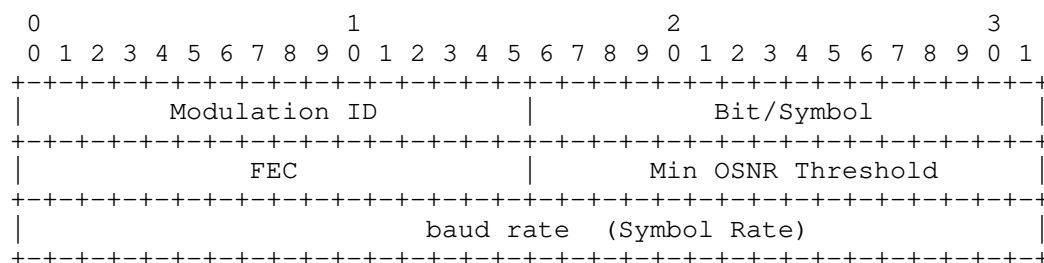


Figure 3: OCh\_General

#### Traffic Type

- Modulation ID (Format) : is the modulation type:  
BPSK, DC DP BPSK, QPSK, DP QPSK, 8QAM, 16QAM,  
32QAM, 64QAM, etc.
- Bits/Symbol(BPS) this indicates the bit per symbol in case of hybrid modulation format. It is an off-set with values from 0 to 127 to be applied to the specified Modulation Format and indicates the mix between the selected Modulation Format and its upper adjacent modulation format.  
(e.g. QPSK + 63 BPS indicates that there is a 50% MIX between QPSK and 8-QAM = 2.5 bits per symbol) If value = 0 the standard Modulation Format is applied.
- FEC: the signal Forward Error Corrections type (16-bit unsigned integer), the defined values are:
  - Value 0 is reserved to be used if no value is defined
- Min OSNR Threshold: An integer specifying the minimum accepted threshold for the Optical Signal-Noise Ratio in 0.1 nm.
- Baud Rate: the signal symbol rate (IEEE 32-bit float, in bauds/s)
  - Value 0 is reserved to be used if no value is defined

#### Notes:

- The Path message from the E.C. can specify all or only a subset of the parameters (e.g. the Modulation and the baud rate as required but not the FEC) setting to 0 for the undefined parameters.  
When forwarding the Path message, the C.N. will set the undefined parameters based on the optical impairment calculation and the constraints given by the E.N.
- Custom codes (values > 0x8000) interpretation is a local installation matter.

#### TLV Usage in RSVP-TE messages:

- Path from the head E.N.: used to force specific transponder configurations
- Path from the tail C.N.: set selected configuration on head node
- Resv from the head C.N.: set selected configuration on tail node

#### 4.2.2. Sub-carrier List Content TLV

For Each carrier inside the Media Channel the TLV is used.

The format of this sub-object (Type = TBA, Length = TBA)  
is as follows:

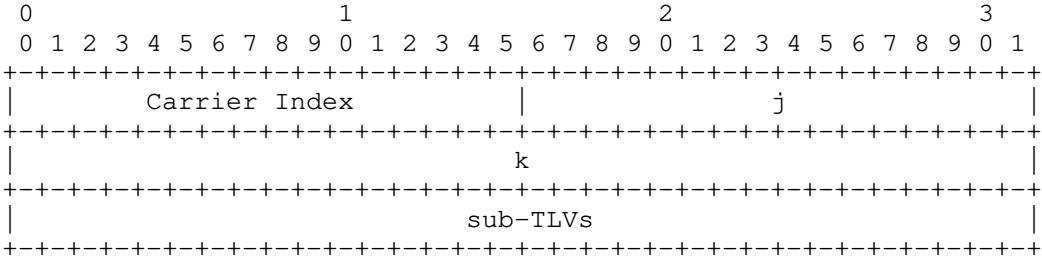


Figure 4: Sub-Carrier parameters



## Source Port Identifier

The format of this sub-object (Type = TBA, Length = 8) is as follows:

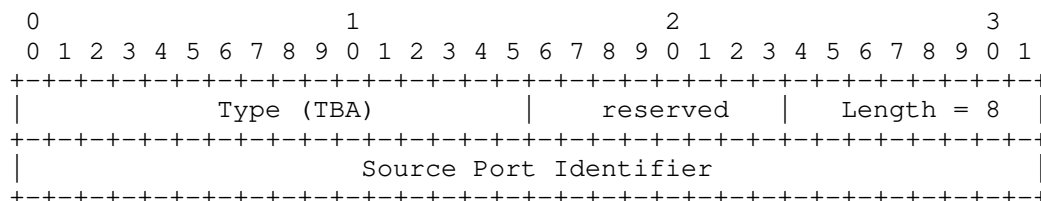


Figure 5: Source Port Identifier

Source Port Identifier: the HEAD E.N. optical logical source end point identifier (32-bits integer, ifindex). In case of UUID usage the parameter could be extended to 128 bits)

## TLV Usage in RSVP-TE message:

- path from the head E.N.: used to force specific carrier ports [optional use, e.g. with external PCE scenario]
- Path from the tail C.N.: report selected carrier head ports to tail C.N.
- Resv: report selected configuration to head E.N.

## Destination Port Identifier

The format of this sub-object (Type = TBA, Length = 8) is as follows:

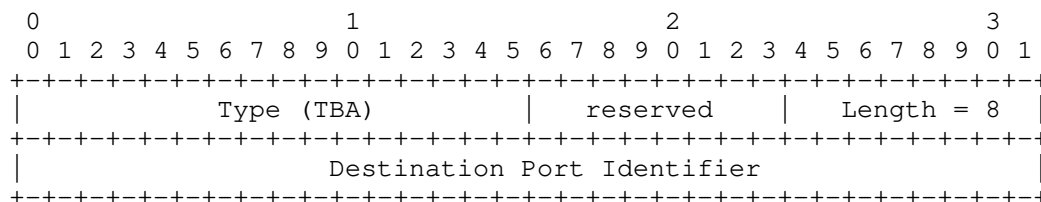


Figure 6: Destination Port Identifiers

Destination Port Identifier: the local upstream optical logical destination end point identifier (32-bits integer, ifindex), In case of UUID usage the parameter could be extended to 128 bits)

TLV Usage in RSVP-TE messages:

- Path from head E.N.: used to force specific carrier ports [optional use, e.g. with external PCE scenario]
- Path from tail C.N.: set selected configuration on tail node
- Resv: report selected configuration to the head E.N.

Carrier Power

The format of this sub-object (Type = TBA, Length = 8) is as follows:

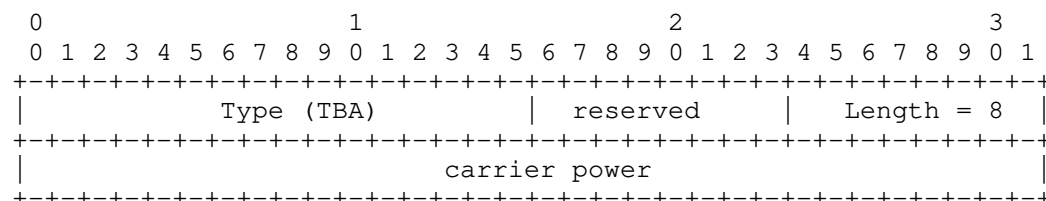


Figure 7: Carrier Power

Carrier Power: the requested carrier transmit power (32-bits IEEE Float, dBm), optionally used to notify the configured power (from E.N. to C.N.) or force the power to from the C.N. to the E.N.

TLV Usage in RSVP-TE messages:

- Path from head the E.N.: used to force specific carrier frequency/ports (optional use, e.g. with external PCE scenario)
- Path from tail C.N.: set selected configuration on tail node
- Resv from the head C.N.: set selected configuration on head node

#### 4.3. RSVP Protocol Extensions Considerations

The additional information described in the draft, is related to the Media Channel supported traffic. The parameters to be used by the egress transceivers are carried in Path messages. In RSVP-TE signaling, hop-specific information is encoded within the ERO as hop attributes and WDM parameters are to be carried as sub-TLVs within the Type 4 TLV [RFC7689], in the Hop Attributes SubObject



Beside, some of the additional information defined is local to the head/tail UNI link (e.g. the carrier/port association), while the traffic spec info should be valid end-to-end.

There can be different methods to model and signal the carriers as described in draft-ietf-ccamp-optical-impairment-topology-yang. The Media Channel, Network Media Channel and labels are well modelled by the RFC7698, RFC7699 and RFC7792 reflecting the ITU-T Recommendations G.694.1 and G.698.2.

Some work is in progress in ITU-T SG15/Q12 to define Network Media Channel (group) that is capable of accommodating the optical tributary signals (OTSi) belonging to optical tributary signal group (OTSiG) (see new ITU-T Draft Recommendation G.807).

Other the encoding proposal reported in this draft, there are at least two other methods to describe the parameters. An option is to describe the OTSi carrier frequency relative to the anchor frequency 193.1THz based on a well-defined granularity (e.g. OTSi carrier frequency = 193100 (GHz) + K \* granularity (GHz) where K is a signed integer value). A second option is to explicitly describe the OTSi carrier frequency and the OTSi signal width in GHz with a certain accuracy.

The second option which is independent of the n, m values already defined in ITU-T Recommendation G.694.1. The OTSi carrier frequency is described in GHz with 3 fractional digits (decimal 64 fraction digits 3). The OTSi signal width is described in GHz with 3 fractional digits (decimal 64 fraction digits 3) and includes the signal roll off as well as some guard band.

The accuracy of 0.001 GHz does not impose a requirement on the optical transceiver components (optical transmitter) in terms of carrier frequency tunability precision. Today's components typically provide a tunability precision in the range of 1..1.5GHz (carrier frequency offset compared to the configured nominal carrier frequency).

Future components may provide a better precision as technology evolves. If needed, a controller may retrieve the transceiver properties in terms of carrier frequency tunability precision in order to be capable of properly configuring the underlying transceiver.

NOTE FROM THE EDITORS: As this description is arbitrarily proposed by the authors to cover a lack of information in IETF and ITU-T, a liaison request to ITU-T is needed. The authors are willing to contribute to Liaison editing and to consider any feedback and proposal from ITU-T.

## 5. Security Considerations

RSVP-TE message security is described in [RFC5920]. IPsec and HMAC-MD5 authentication are common examples of existing mechanisms. This document only defines new UNI objects that are carried in existing UNI messages, thus it does not introduce new security considerations.

## 6. IANA Considerations

The IANA is requested to create, within the "GMPLS Signaling Parameters" registry, two new sub-registries named "WDM Modulation Formats" and "WDM FEC Types".

For both of them:

- o the value 0 means "Pending selection",
- o the range 1-65503 follows the Expert Review policy for registration,
- o the range 65504-65535 is for experimental use.

The "WDM Modulation Format" sub-registry is initialized as follows:

Value	Modulation Format
0	Pending selection
1	DPSK
2	QPSK
3	8-QAM
4	16-QAM
5	32-QAM
6	64-QAM
7-63999	Unallocated
64000-65535	Vendor specific use

The "WDM FEC Types" sub-registry is initialized as follows:

Value	FEC Types
0	Pending selection
1	Reed Solomon FEC
2	Staircase FEC
3	O-FEC.
4-63999	Unallocated
64000-65535	Vendor specific use

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A framework for Management and Control of DWDM optical interface  
parameters  
draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk-06

## Abstract

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

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## 1. Introduction

The usage of the single channel DWDM interfaces (e.g. in routers) connected to a DWDM Network (which include ROADMs and optical amplifiers) adds a further networking option for operators allowing new scenarios but require harmonised control and management plane interaction between different network domains.

Carriers deploy their networks today based on transport und packet network infrastructures as domains to ensure high availability and a high level of redundancy. Both network domains were operated and managed separately. This is the status quo in many carrier networks today. In the case of deployments, where the optical transport interface moves into the client device (e.g. router) an interaction between those domains becomes necessary.

This framework specifies different levels of control and management plane interaction to support the usage of single channel optical interfaces in carrier networks in an efficient manner.

The objective of this document is to provide a framework for the control and management of transceiver interfaces based on the corresponding use cases and requirements to ensure an efficient and optimized data transport.

Optical routing and wavelength assignment based on WSON is out of scope although can benefit of the way the optical parameters are exchanged between the Client and the DWDM Network. Also, the wavelength ordering process and the process how to determine the demand for a new wavelength path through the network is out of scope.

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

### 1.1. Requirements Language

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

## 2. Terminology and Definitions

The current generation of WDM networks are single vendor networks where the optical line system and the transponders are tightly integrated. The DWDM interfaces migration from the transponders to the colored interfaces change this scenario, by introducing a

standardized interface at the level of OCh between the DWDM interface and the DWDM network.

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

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

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

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

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

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

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

**Control Plane [G.8081]:** The control plane performs neighbour discovery, call control and connection control functions. Through signalling, the control plane sets up and releases connections, and may restore a connection in case of a failure. The control plane

also performs other functions in support of call and connection control, such as neighbour discovery and routing information dissemination.

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

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

### 3. Solution Space

The solution space of this document is focusing on aspects related to the management and control of single-channel optical interface parameters of physical point-to-point and ring DWDM applications on single-mode optical fibres and allows the direct connection of a wide variety of equipment using a DWDM link, for example

1. A digital cross-connect with multiple optical interfaces, supplied by a different vendor from the line system
2. Devices as routing, switching or compute nodes, each from a different vendor, providing optical line interfaces
3. A combination of the above

#### 3.1. Comparison of approaches for transverse compatibility

This section describes two ways to achieve transverse compatibility. Section 3.1.1 describes the classic model based on well defined inter-domain interfaces. Section 3.1.2 defines a model ensuring interoperability on the line side of the optical network.

##### 3.1.1. Multivendor DWDM line system with transponders

As illustrated in Figure 1, for this approach interoperability is achieved via the use of optical transponders providing OEO (allowing conversion to appropriate parameters). The optical interfaces can then be any short reach standardized optical interface that both vendors support, such as those found in [ITU-T G.957] [ITU-T G.691], [ITU-T G.693], [ITU-T G.959.1], etc.

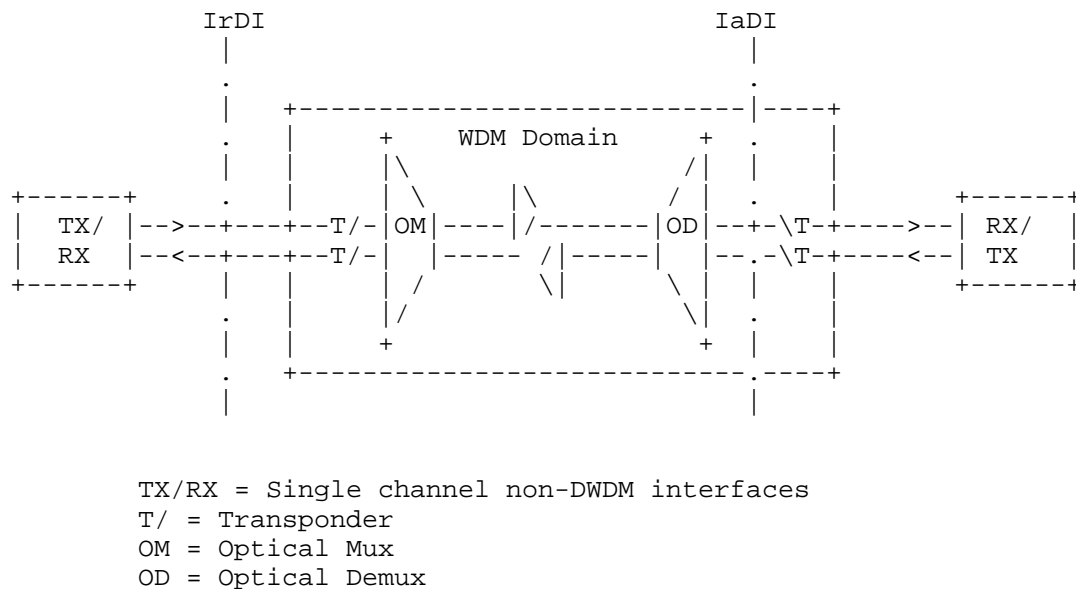


Figure 1: Inter and Intra-Domain Interface Identification

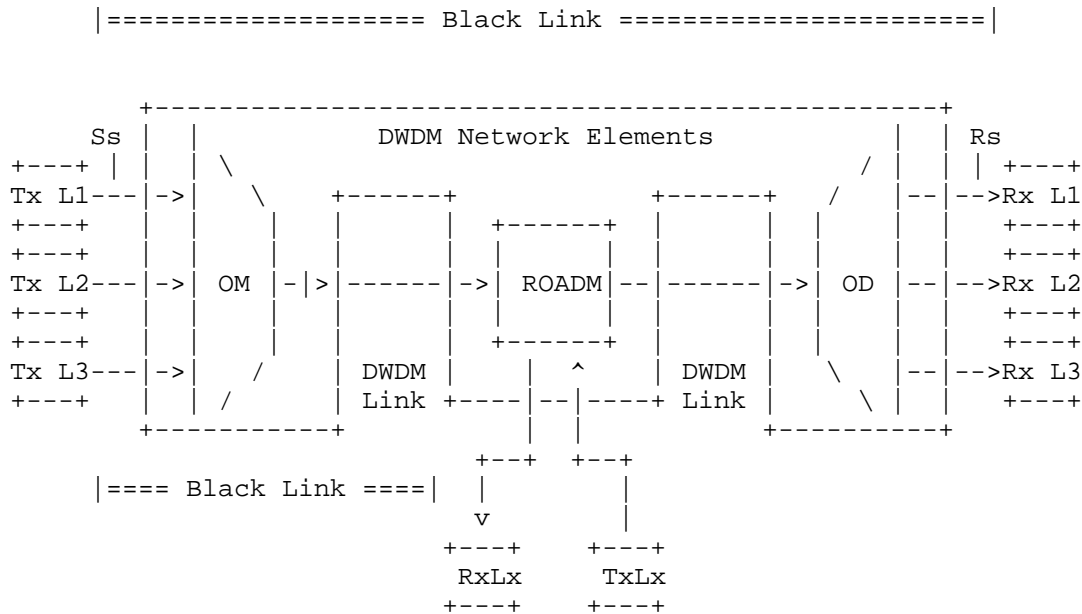
In the scenario of Figure 1 the administrative domain is defined by the Interdomain Interface (IrDI). This interface terminates the DWDM domain. The line side is characterized by the IaDI. This interface specifies the internal parameter set of the optical administrative domain. In the case of a client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

This document elaborates only the IaDI Interface as shown in Figure 1 as transversely compatible and multi-vendor interface within one administrative domain controlled by the network operator.

### 3.1.2. Integrated single channel DWDM deployments on the client site

In case of a deployment as shown in Figure 2, through the use of DWDM interfaces, multi-vendor interconnection can also be achieved while removing the need for one short reach transmitter and receiver pair per channel (eliminating the transponders).

Figure 2 shows a set of reference points, for single-channel connection (Ss and Rs) between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an optical multiplexer (OM) and an optical demultiplexer (OD) (which are used as a pair with the peer element), one or more optical amplifiers and may also include one or more OADMs.



Ss = Reference point at the DWDM network element tributary output  
Rs = Reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

Linear DWDM network as per ITU-T G.698.2

Figure 2: Linear Black Link

The single administrative domain may consist of several vendor domains. Even in that case a common network management and control is required to ensure a consistent operation and provisioning of the entire connection.

The following documents [DWDM-interface-MIB], [YANG], [LMP] define such a protocol- FIX-THE-REFERENCE specific information using SNMP/ SMI, Yang models and LMP TLV to support the direct exchange of information between the client and the network management and control plane.

#### 4. Solutions for managing and controlling single channel optical interface

Operation and management of WDM systems is traditionally seen as a homogenous group of tasks that could be carried out best when a single management system or an umbrella management system is used. Currently each WDM vendor provides an Element Management System (EMS) that also provisions the wavelengths. In a multi-vendor line system, such single-vendor EMS requirement is no more effective. New methods of managing and controlling line systems need to be looked at.

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

1. Separate operation and management of client device and the transport network whereas the interface of the client belongs to the administrative domain of the transport network and will be managed by the transport group. This results in two different approaches to send information to the management system
  - a. Direct connection from the client to the management system, ensuring a management of the DWDM interface of the optical network (e.g. EMS, NMS)
  - b. Indirect connection to the management system of the optical network using a protocol (LMP) between the client device and the directly connected WDM system node to exchange management information with the optical domain
2. Common operation and management of client device including the single channel DWDM part and the Transport network

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

The second solution addresses the case where underlying WDM transport network is mainly used to interconnect a homogeneous set of client

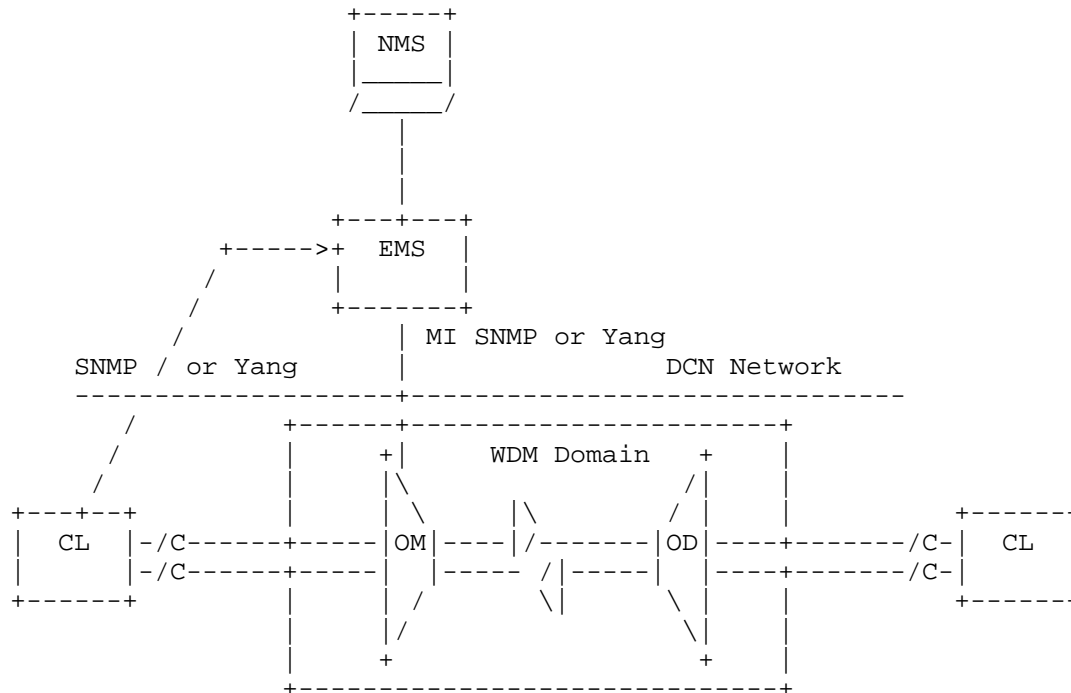
nodes (e.g. IP routers or digital crossconnects). Since the service creation and restoration could be done by the higher layers (e.g. IP), this may lead to an efficient network operation and a higher level of integration.

#### 4.1. Separate Operation and Management Approaches

##### 4.1.1. Direct connection to the management system



As depicted in Figure 3 (case 1a) one possibility to manage the optical interface within the client domain is a direct connection to the management system of the optical domain. This ensures manageability as usual.



CL = Client Device  
 /C = Single Channel Optical Interface  
 OM = Optical Mux  
 OD = Optical Demux  
 EMS = Element Management System  
 MI = Management Interface  
 DCN = Data Control Network

Figure 3: Connecting Single Channel optical interfaces to the Transport Management system

The exchange of management information between client device and the management system assumes that some form of a direct management communication link exists between the client device and the DWDM management system (e.g. EMS). This may be an Ethernet Link or a DCN connection (management communication channel MCC).

It must be ensured that the optical network interface can be managed in a standardized way to enable interoperable solutions between different optical interface vendors and vendors of the optical network management application. RFC 3591 [RFC3591] defines managed objects for the optical interface type but needs further extension to cover the optical parameters required by this framework document. Therefore an extension to this MIB for the optical interface has been drafted in [DWDM-interface-MIB]. SNMP is used to read parameters and get notifications and alarms, netconf and yang models are needed to easily provision the interface with the right parameter set as described in [YANG]

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

- 4.1.2. Indirect connection to the DWDM management system (first optical node)

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

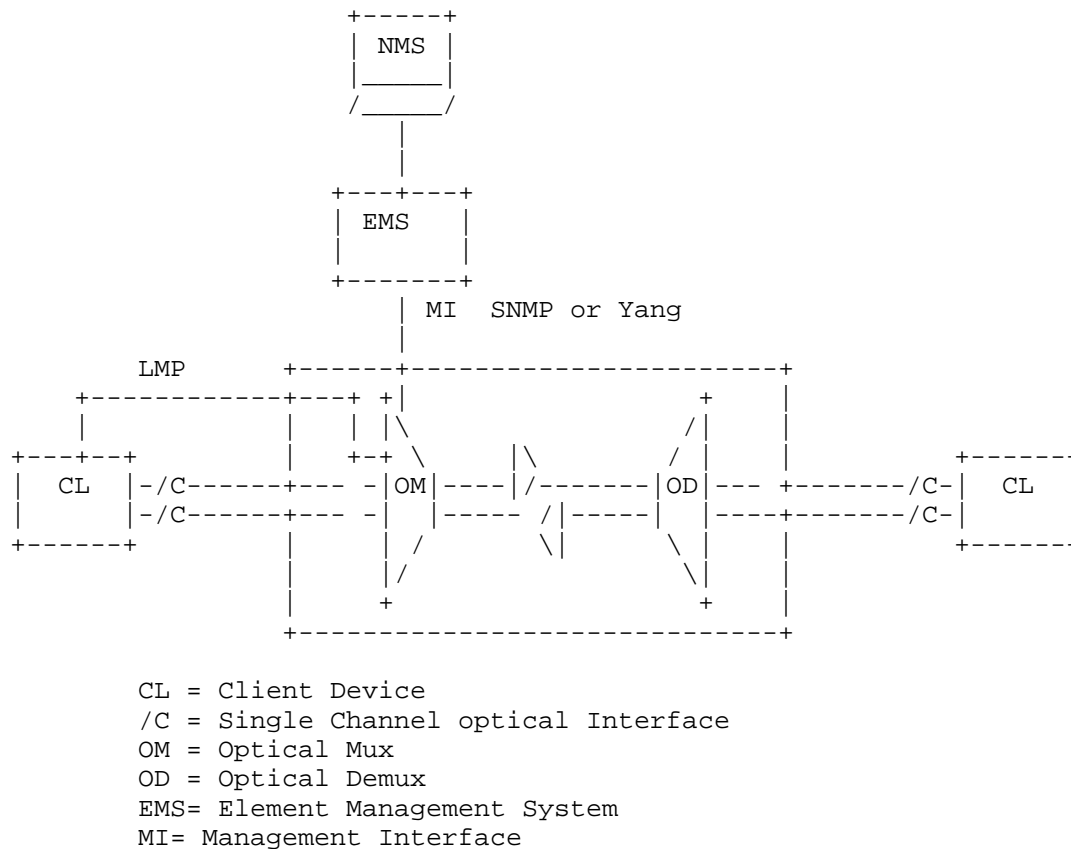


Figure 4: Direct connection between peer node and first optical network node

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

The LMP based on RFC 4209 does not yet support the transmission of configuration data (information). This functionality must be added to the existing extensions of the protocol. The use of LMP-WDM assumes that some form of a control channel exists between the client

node and the WDM equipment. This may be a dedicated lambda or an Ethernet Link.

#### 4.2. Control Plane Considerations

The concept of integrated single channel DWDM interfaces equally applies to management and control plane mechanisms. GMPLS control plane protocols have been extended for WSON, e.g. [RFC7689] for fixed grid signal and for flexi-grid [RFC7792]. One important aspect of the [G.698.2] is the fact that it includes the wavelength that is supported by the given link. Therefore, the link can logically be considered as a fiber that is transparent only for a single wavelength. In other words, the wavelength becomes a characteristic of the link itself.

Nevertheless the procedure to light up the fiber may vary depending on the implementation. Since the implementation is unknown a priori, different sequences to light up a wavelength need to be considered:

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

The preferred way to address these in a Control Plane enabled network is neighbour discovery including exchange of link characteristics and link property correlation. The general mechanisms are covered in RFC4209 [LMP-WDM] and RFC 4204[LMP] which provides the necessary

protocol framework to exchange those characteristics between client and black link. LMP-WDM is not intended for exchanging routing or signaling information nor to provision the lambda in the transceiver but covers:

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

Extensions to LMP/LMP-WDM covering the parameter sets (application codes) are needed. Additionally, when client and server side are managed by different operational entities, link state exchange is required to align the management systems.

#### 4.2.1. Considerations using GMPLS signaling

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

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

- a. Using RSVP-TE only for the signalling and LMP as described above to exchange information to configure the optical interface within the edge node or
- b. RSVP-TE (typically with loose ERO) to transport additional information
- c. Leaking IGP information instead of exchanging this information needed from the optical network to the edge node (UNI will be transformed to a border-peer model, see RFC 5146)

Furthermore following issues should be addressed:

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

b) Due to the bidirectional wavelength path that must be setup, the upstream edge node must include a wavelength value into the RSVP-TE Path message. But in the case of a UNI model the client device may not have full information about which wavelength must/should be selected, whereas this information must be exchanged between the edge and the core node. The special value defined in [Network-Assigned-Upstream-Label] allows the optical network to assign the actual wavelength to be used by the upstream transponder, which is a simple and efficient solution to this issue.

## 5. Use cases

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

### 5.1. Service Setup

It is necessary to differentiate between different operational issues for setting up a light path (a DWDM connection is specific in having defined maximum impairments) within an operational network.

The first step is to determine if transceivers located at different end-points are interoperable, i.e. support a common set of operational parameters. In this step it is required to determine transceiver capabilities in a way to be able to correlate them for interoperability purposes. Such parameters include modulation scheme, modulation parameters, FEC to name a few. If both transceivers are controlled by the same NMS or CP, such data is readily available. However in cases like Fig.4 a protocol need to be used to inform the controlling instance (NMS or CP) about transceiver parameters. It is suggested to extend LMP for that purpose.

The second step is to determine the feasibility of a lightpath between two transceivers without applying an optical signal. Understanding the limitations of the transceiver pair, a route through the optical network has to be found, whereby each route has

an individual set of impairments deteriorating a wavelength traveling along that route. Since a single transceiver can support multiple parameter sets, the selection of a route may limit the permissible parameter sets determined in step1.

The third step is then to setup the connection itself and to determine the Wavelength. This is done using the NMS of the optical transport network or by means of a control plane interaction such as signaling and includes the route information as well as the parameter set information necessary to enable communication.

In a fourth step, Optical monitoring is activated in the WDM network in order to monitor the status of the connection. The monitor functions of the optical interfaces at the terminals are also activated in order to monitor the end to end connection.

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

## 5.2. Link monitoring Use Cases

The use cases described below are assuming that power monitoring functions are available in the ingress and egress network element of the DWDM network, respectively. By performing link property correlation it would be beneficial to include the current transmit power value at reference point Ss and the current received power value at reference point Rs. For example if the Client transmitter power has a value of 0dBm and the ROADM interface measured power is -6dBm the fiber patch cord connecting the two nodes may be pinched or the connectors are dirty. As discussed before, the actual route or selection of a specific wavelength within the allowed set is outside the scope of LMP. The computing entities (e.g. the first optical node originating the circuit) can rely on GMPLS IGP (OSPF) to retrieve all the information related to the network, calculate the path to reach the endpoint and signal the path implementation through the network via RSVP-TE.

G.698.2 defines a single channel optical interface for DWDM systems that allows interconnecting network-external optical transponders across a DWDM network. The optical transponders are external to the DWDM network. This so-called 'black link' approach illustrated in Figure 5-1 of G.698.2 and a copy of this figure is provided below. The single channel fiber link between the Ss/Rs reference points and the ingress/egress port of the network element on the domain boundary of the DWDM network (DWDM border NE) is called access link in this contribution. Based on the definition in G.698.2 it is part of the

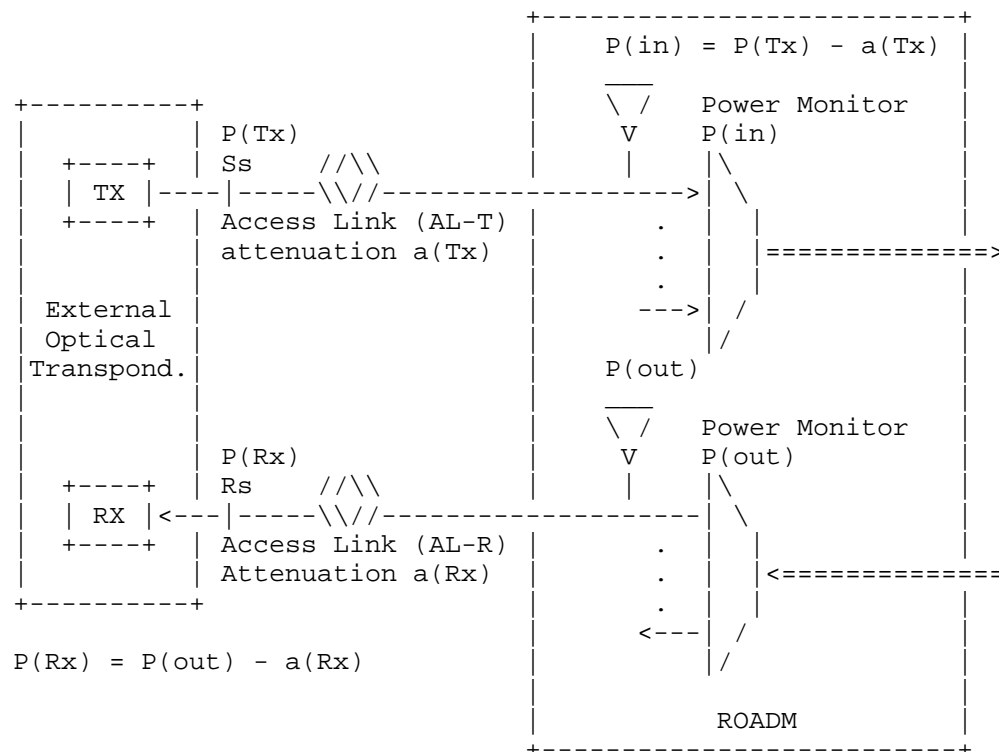
DWDM network. The access link is typically realized as a passive fiber link that has a specific optical attenuation (insertion loss). As the access link is an integral part of the DWDM network, it is desirable to monitor its attenuation. Therefore, it is useful to detect an increase of the access link attenuation, for example, when the access link fiber has been disconnected and reconnected (maintenance) and a bad patch panel connection (connector) resulted in a significantly higher access link attenuation (loss of signal in the extreme case of an open connector or a fiber cut). In the following section, two use cases are presented and discussed:

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

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



Figure 5 Access Link Power Monitoring



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

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

- $P(\text{in}) < P(\text{Tx}) - a(\text{Tx}) - t$  (Tx direction)
- $P(\text{Rx}) < P(\text{out}) - a(\text{Rx}) - t$  (Rx direction)
- $a(\text{Tx}) = a(\text{Rx})$

Figure 5: Extended LMP Model

### 5.2.1. Pure Access Link (AL) Monitoring Use Case

Figure 6 illustrates the access link monitoring use case and the different physical properties involved that are defined below:

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

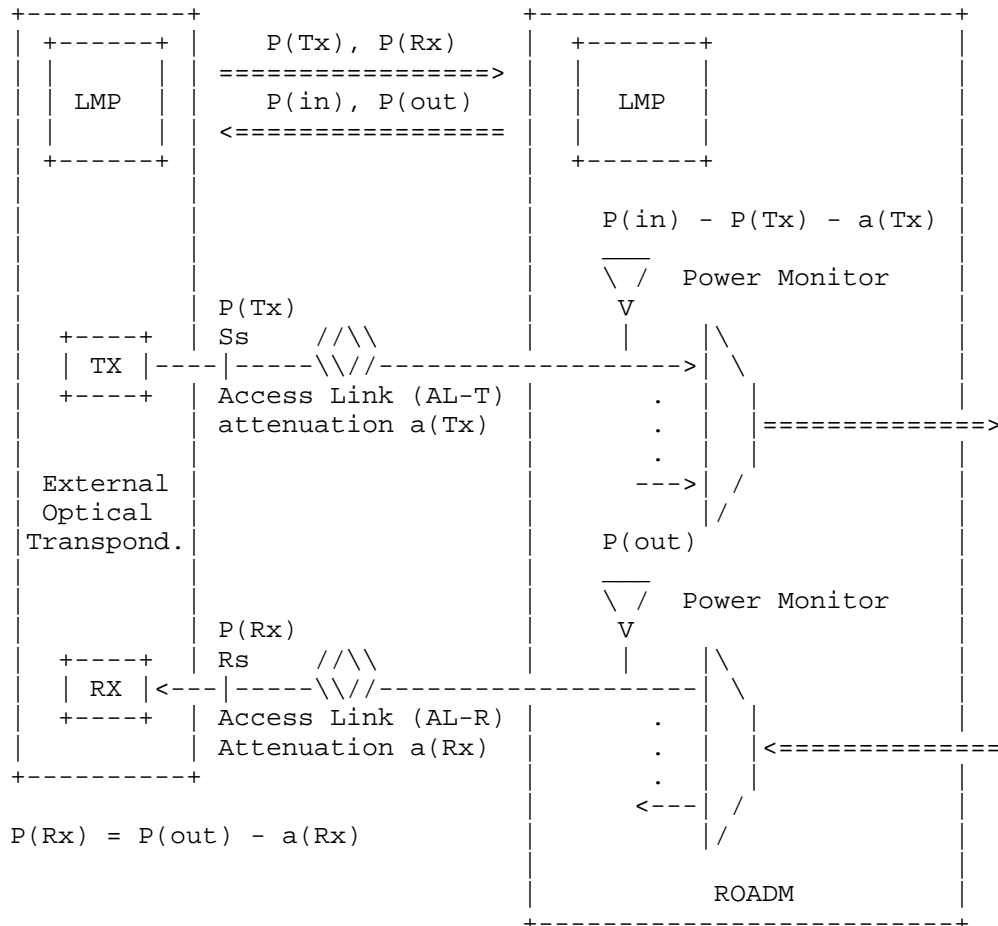
Description:

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

Access Link monitoring process:

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

Figure 6 Use case 1: Access Link monitoring



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

Figure 6: Extended LMP Model

### 5.2.2. Power Control Loop Use Case

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

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

Figure 7 Use case 2: Power Control Loop

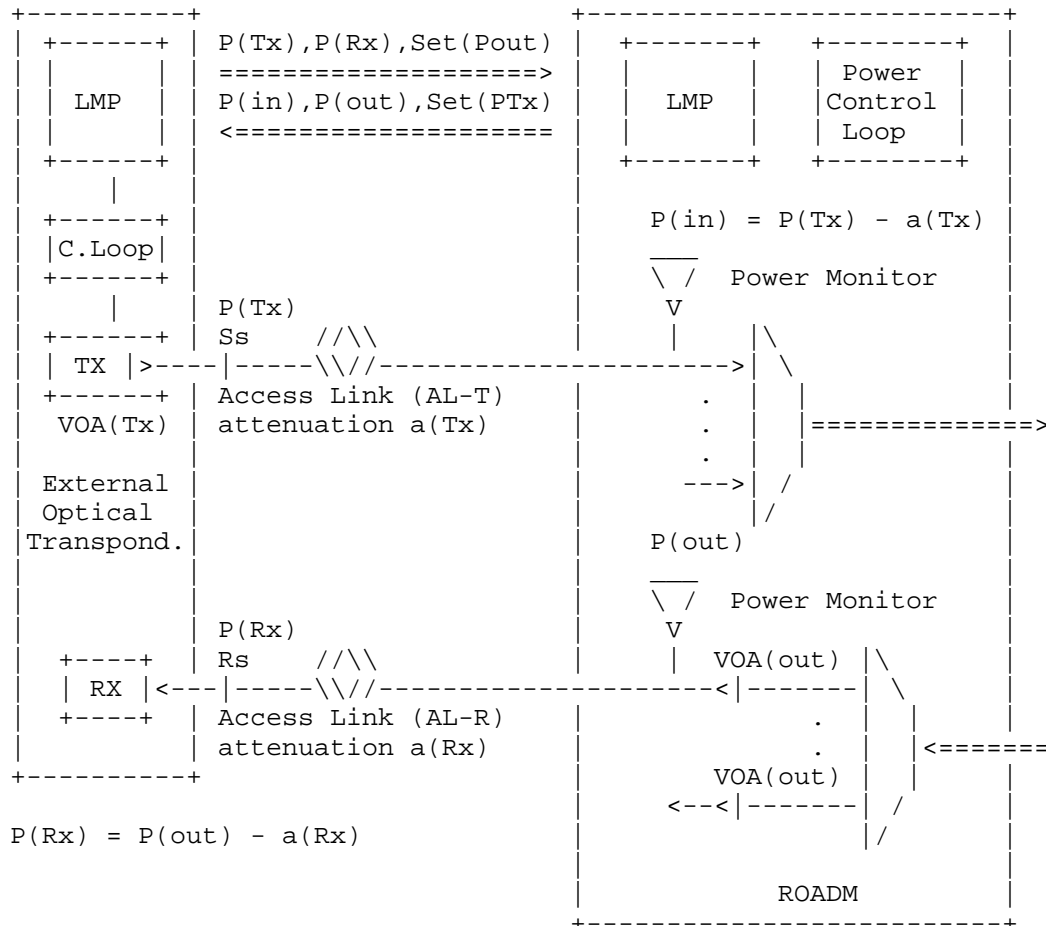


Figure 7: Power control loop

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

## 6. Requirements

Even if network architectures becomes more complex the management and operation as well as the provisioning process should have a higher degree of automation or should be fully automated. Simplifying and automating the entire management and provisioning process of the network in combination with a higher link utilization and faster restoration times will be the major requirements that has been addressed in this section.

Data Plane interoperability as defined for example in [ITU.G698.2] is a precondition to ensure plain solutions and allow the usage of standardized interfaces between network and control/management plane.

The following requirements are focusing on the usage of DWDM interfaces.

- 1 To ensure a lean management and provisioning process of single channel interfaces management and control plane of the client and DWDM network must be aware of the parameters of the interfaces and the optical network to properly setup the optical connection.
- 2 A standard-based northbound API (to network management system) based on Netconf should be supported, alternatively SNMP could be supported too.
- 3 A standard-based data model for single channel interfaces must be supported to exchange optical parameters with control/management plane.
- 4 Netconf should be used also for configuration of the single channel interfaces including the power setting
- 5 LMP should be extended and used in cases where optical parameters need to be exchanged between peer nodes to correlate link characteristics and adopt the working mode of the single channel interface.
- 6 LMP may be used to adjust the output power of the single channel DWDM interface to ensure that the interface works in the right range.
- 7 RSVP-TE may be used to exchange some relevant parameters between the client and the optical node (e.g. the label value), without preventing the network to remain in charge of the optical path computation
- 8 Power monitoring functions at both ends of the DWDM connection should be used to further automate the setup and shutdown process of the optical interfaces.
- 9 A standardized procedure to setup an optical connection should be defined and implemented in DWDM and client devices (containing the single channel optical interface).
- 10 Pre-tested and configured backup paths should be stored in so called backup profiles. In fault cases this wavelength routes should be used to recover the service.
- 11 LMP may be used to monitor and observe the access link.

## 7. Acknowledgements

The authors would like to thank all who supported the work with fruitful discussions and contributions.

## 8. IANA Considerations

This memo includes no request to IANA.

## 9. Security Considerations

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

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

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

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A framework for Management and Control of DWDM optical interface  
parameters  
draft-ietf-ccamp-dwdm-if-mng-ctrl-fwk-13

## Abstract

The control and management of DWDM interfaces are a precondition for enhanced multilayer networking. They are needed to ensure an efficient data transport, to meet the requirements requested by today's IP-services and to provide a further automation of network provisioning and operations. This document describes use cases, requirements and solutions for the control and management of optical interface parameters according to different types of single channel DWDM interfaces. The focus is on automating the network provisioning process irrespective on how it is triggered i.e. by Element Manager System (EMS), Network Management System (NMS) or Generalized Multi Protocol Label Switching (GMPLS). This document covers management and control considerations in different scenarios of single channel DWDM interfaces. The purpose is to identify the necessary information and processes to be used by control or management systems to properly and efficiently drive the network.

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## 1. Introduction

The usage of external single channel Dense Wavelength Division Multiplexing (DWDM) interfaces (e.g. in routers) connected to a DWDM Network (e.g. router connected to a network of Reconfigurable Optical Add Drop Multiplexers (ROADM) and optical amplifiers) adds a further networking option for operators but requires an harmonised control and management plane interaction between the different network domains.

Carriers deploy their networks today based on transport and packet network infrastructures as domains to ensure high availability and a high level of redundancy combining the Packet and Transport restoration. Both network domains were operated and managed separately. This is the status quo in many carrier networks today. In the case of deployments where the optical transport interface moves into the client device (e.g. router) an interaction between those domains becomes necessary (e.g. Lambda reprovisioning due to an optical restoration).

This framework specifies different levels of control and management plane interaction to support the usage of single channel optical interfaces in carrier networks in an efficient manner. The interfaces between the two layers can be either gray or coloured.

Although Optical routing and wavelength assignment based on Wavelength Switched Optical Network (WSN) is out of scope, they can benefit from the optical parameters that are exchanged between the Client and the DWDM Network. Also, the wavelength ordering process and determining the demand for a new wavelength path through the network are out of scope. The GMPLS and PCE functions will use the information collected from the Client and the DWDM network, the definition on how PCE and GMPLS can use the information and cooperate to implement RWA and circuit/service provisioning are out of scope of this document.

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

## 1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP\_14, RFC 2119 [RFC2119], RFC 8174 [RFC8174] when, and only when, they appear in all capitals, as shown here.

While RFC 2119 [RFC2119] RFC 8174 [RFC8174] describe interpretations of these key words in terms of protocol specifications and implementations, they are used in this document to describe design requirements for protocol extensions.

## 2. Terminology and Definitions

The current generation of Wavelength Division Multiplexing (WDM) networks are single vendor networks where the optical line system and the transponders are tightly integrated. The DWDM interface migration from integrated transponders to third party transponders or colored interfaces change this scenario and introduces a standardized interface at the level of OCh between the DWDM interface and the DWDM network.

**Black Link:** The Black Link [ITU-T.G.698.2] allows supporting an optical transmitter/receiver pair (of a single vendor or from different vendors) to provide a single optical channel interface and transport it over an optical network composed of amplifiers, filters, add-drop multiplexers these being possibly from different vendors. Therefore the standard defines the ingress and egress parameters for the optical interfaces at the reference points Source side (Ss) and Receive side (Rs).

**Single Channel DWDM Interface:** The single channel interfaces to DWDM systems defined in [ITU-T.G.698.2], which currently include the following features: channel frequency spacing: 50 GHz and wider (defined in [ITU-T.G.694.1] ); bit rate of single channel: Up to 100 Gbit/s. Future revisions are expected to include application codes for bit rates up to 400 Gbit/s.

**Forward Error Correction (FEC):** FEC is a way of improving the performance of high-capacity optical transmission systems. Employing FEC in optical transmission systems yields system designs that can accept relatively large BER (much more than  $10^{-12}$ ) in the optical transmission line (before decoding).

**Administrative domain [ITU-T.G.805]:** the extent of resources which belong to a single player such as a network operator, a service



provider or an end-user. Administrative domains of different players do not overlap amongst themselves.

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

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

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

Control Plane [ITU-T.G.8081]: Through signaling, the control plane sets up and releases connections, may restore a connection in case of a failure, and also performs other functions (e.g., neighbor discovery, topology distribution) in support of those.

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

Line System: A Line System is a portion of the network including Reconfigurable Add Drop Multiplexers (ROADM) Line Amplifiers and the the fibers connecting them.

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

### 3. Solution Space

The solution space of this document is focusing on aspects related to the management and control of single-channel optical interface parameters of physical point-to-point and ring DWDM applications on single-mode optical fibres and allows the direct connection of a wide variety of equipment using a DWDM link, for example

1. A digital cross-connect with multiple optical interfaces, supplied by a different vendor from the line system
2. Devices as routing, switching or compute nodes, each from a different vendor, providing optical line interfaces

3. A set of Data Center Equipment and servers

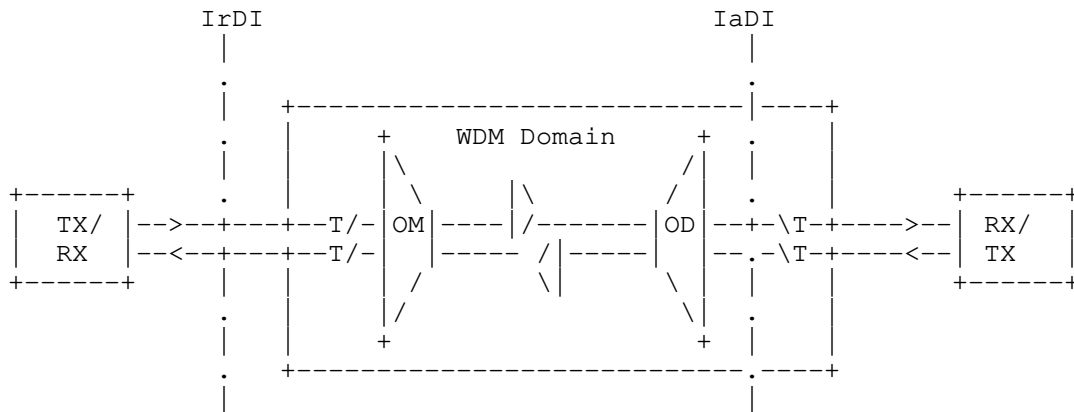
4. A combination of the above

### 3.1. Comparison of Approaches for Transverse Compatibility

This section describes two ways to achieve transverse compatibility. Section 3.1.1 describes the classic model based on well defined inter-domain interfaces. Section 3.1.2 defines a model ensuring interoperability on the line side of the optical network.

#### 3.1.1. Multivendor DWDM Line System with Transponders

As illustrated in Figure 1, for this approach interoperability is achieved via the use of optical transponders providing OEO (allowing conversion to appropriate parameters). The optical interfaces can then be any short reach standardized optical interface that both vendors support, such as those found in [ITU-T.G.957], [ITU-T.G.691], [ITU-T.G.693], etc.



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

Figure 1: Inter and Intra-Domain Interface Identification

In the scenario of Figure 1 the administrative domain is defined by the Interdomain Interface (IrDI). This interface terminates the DWDM

domain. The line side is characterized by the Intradomain Interface (IaDI). This interface specifies the internal parameter set of the optical administrative domain. In the case of a client DWDM interface deployment this IaDI moves into the client device and extends the optical and administrative domain towards the client node. [ITU-T.G.698.2] for example specifies a set of parameter set for a certain set of applications, see Section 3.1.2.

This document elaborates only the IaDI (Intra Domain Interface) as shown in Figure 1 as DWDM transversely compatible and multi-vendor interface within one administrative domain controlled by the network operator.

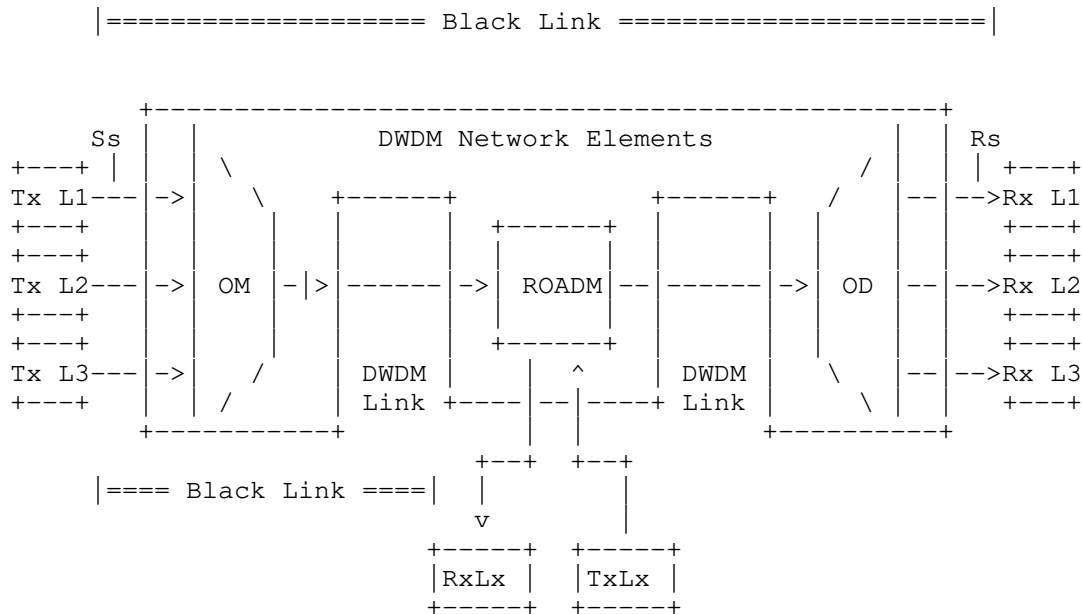
SNMP/Simple Management Interface (SMI), NETCONF/RESTCONF and Link Management Protocol (LMP) TLV to support the direct exchange of information between the client and the network management and control plane will be specified in further documents.

The YANG based NETCONF and RESTCONF protocol are better suited for creating and modifying configuration state and thus RECOMMENDED to be used over SNMP MIB. The SNMP MIB creating and modifying configuration state could be used for legacy network.

### 3.1.2. Integrated Single Channel DWDM Deployments on the Client Site

In case of a deployment as shown in Figure 2, through the use of DWDM interfaces, multi-vendor interconnection can also be achieved. Among the possible use cases, it may be used to remove the need for one short reach transmitter and receiver pair per channel (eliminating the transponders).

Figure 2 shows a set of reference points, for single-channel connection (Ss and Rs) between transmitters (Tx) and receivers (Rx). Here the DWDM network elements include an optical multiplexer (OM) and an optical demultiplexer (OD) (which are used as a pair with the peer element), one or more optical amplifiers and may also include one or more ROADMs.



Ss = Reference point at the DWDM network element tributary output  
Rs = Reference point at the DWDM network element tributary input  
Lx = Lambda x  
OM = Optical Mux  
OD = Optical Demux  
ROADM = Reconfigurable Optical Add Drop Mux

Linear DWDM network as per ITU-T G.698.2

Figure 2: Linear Black Link

The single administrative domain may consist of several vendor domains. Even in that case a common network management and control is required to ensure a consistent operation and provisioning of the entire connection.

SNMP/SMI, NETCONF/RESTCONF and LMP TLV to support the direct exchange of information between the client and the network management and control plane will be specified in further documents.

#### 4. Solutions for Managing and Controlling Single Channel Optical Interface

Operation and management of WDM systems is traditionally seen as a homogenous group of tasks that could be carried out best when a single management system or a hierarchical management system is used. Currently each WDM vendor provides an Element Management System (EMS) that also provisions the wavelengths. In a multi-vendor line system, such single-vendor EMS requirement is no more effective. New methods of managing and controlling line systems need to be looked at.

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

1. Separate operation and management of client device and the transport network whereas the interface of the client belongs to the administrative domain of the transport network and will be managed by the transport group. This results in two different approaches to send information to the management system
  - a. Direct connection from the client node to the transport management system, ensuring a management of the DWDM interface of the optical network (e.g. EMS, NMS)
  - b. Indirect connection to the management system of the optical network using a protocol (e.g. LMP) between the client device and the directly connected WDM system node to exchange management information with the optical domain
2. Common operation and management of client device including the single channel DWDM part and the Transport network

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

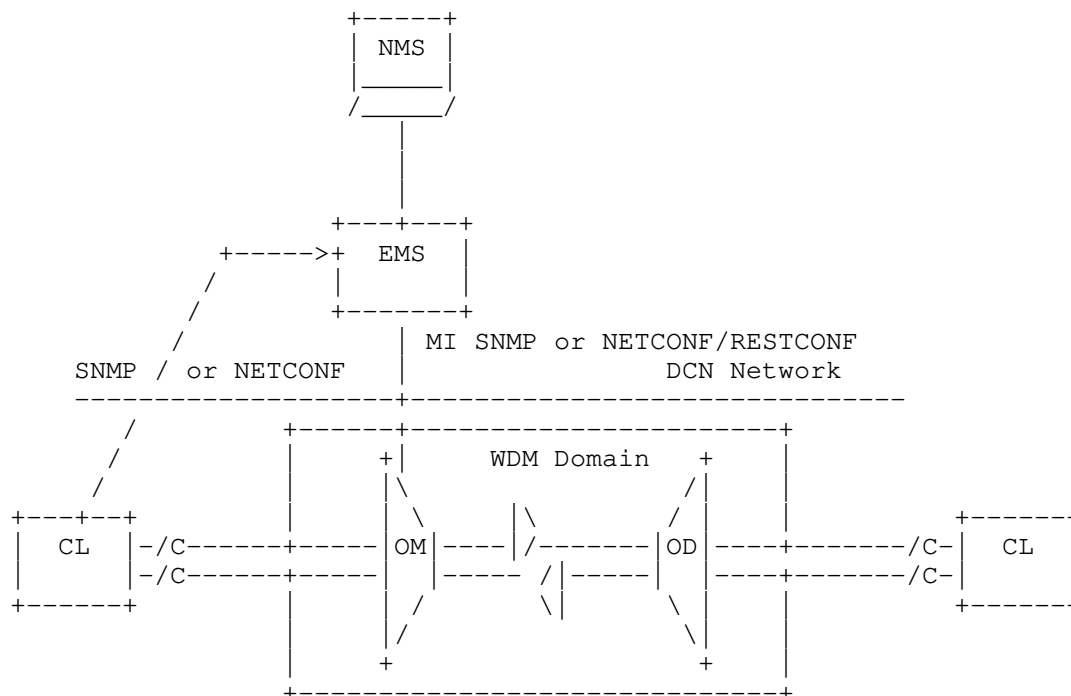
The second solution addresses the case where underlying WDM transport network is mainly used to interconnect a homogeneous set of client nodes (e.g. IP routers or digital crossconnects). Since the service creation and restoration could be done by the higher layers (e.g.

IP), this may lead to an efficient network operation and a higher level of integration.

#### 4.1. Separate Operation and Management Approaches

#### 4.1.1. Direct Connection to the Management System

As depicted in Figure 3 (case 1a) one possibility to manage the optical interface within the client domain is a direct connection to the management system of the optical domain. This ensures manageability as usual.



CL = Client Device  
/C = Single Channel Optical Interface  
OM = Optical Mux  
OD = Optical Demux  
EMS = Element Management System  
MI = Management Interface  
DCN = Data Control Network

Figure 3: Connecting Single Channel optical interfaces to the Transport Management system

The exchange of management information between client device and the management system assumes that some form of a direct management communication link exists between the client device and the DWDM management system (e.g. EMS). This may be an Ethernet Link or a DCN connection (management communication channel MCC).

It must be ensured that the optical network interface can be managed in a standardized way to enable interoperable solutions between different optical interface vendors and vendors of the optical network management application. [RFC3591] defines managed objects for the optical interface type but needs further extension to cover the optical parameters required by this framework document.

Is to be noted that the CL (client device) and the DWDM network are belonging to the same operator so the DWDM EMS and the Client devices are connected to the same DCN and the communication security considerations are applicable to CL as per DWDM devices.

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

#### 4.1.2. Indirect Connection to the DWDM Management System (First Optical Node)

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

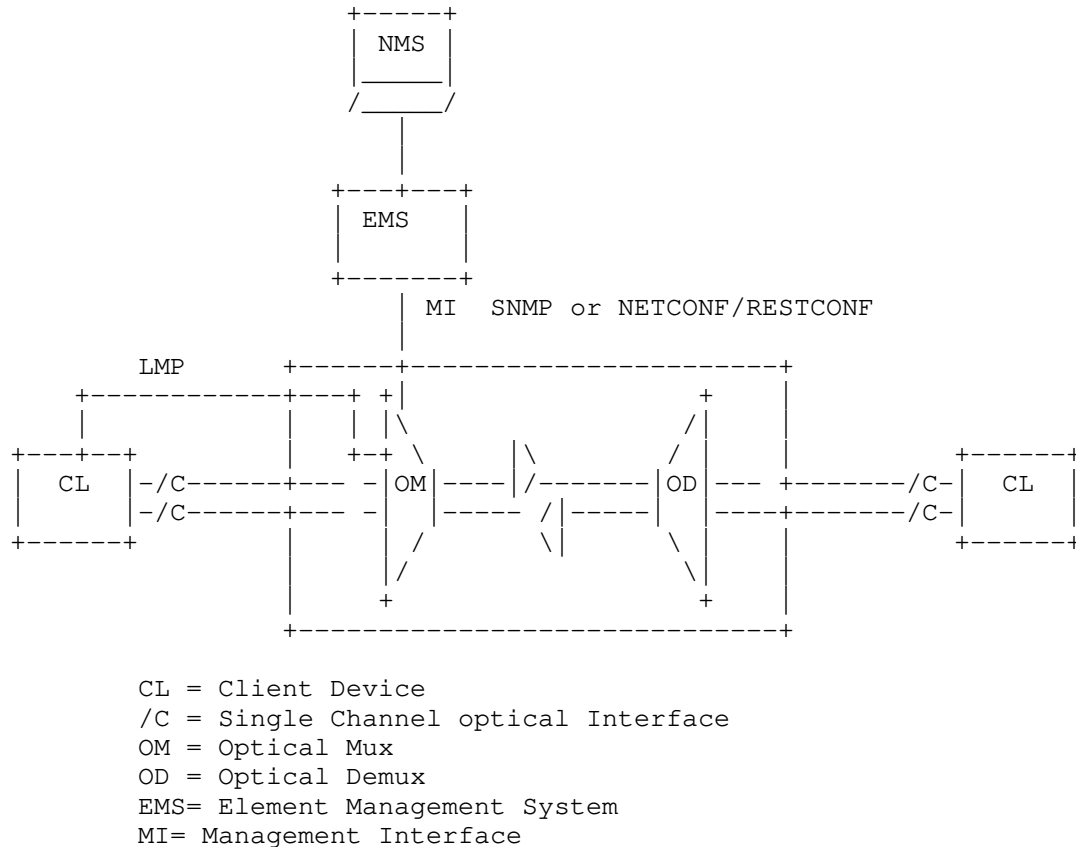


Figure 4: Direct connection between peer node and first optical network node

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

At the time of writing this document, LMP does not yet support the transmission of configuration data (information). This functionality is addressed by draft-ietf-ccamp-dwdm-if-lmp extending the RFC 4209 [RFC4209]. The use of LMP assumes that some form of a control



channel exists between the client node and the WDM equipment. This may be a dedicated lambda or an Ethernet Link.

#### 4.2. Control Plane Considerations

The concept of integrated single channel DWDM interfaces equally applies to management and control plane mechanisms. GMPLS control plane protocols have been extended for WSON, e.g. RFC 7689 [RFC7689] ) for fixed grid signal and for flexi-grid RFC 7792 [RFC7792] ). One important aspect of the Black Link [ITU-T.G.698.2] is the fact that it is specific to the wavelength that is supported by the given link. Therefore, the link can logically be considered as a fiber that is transparent only for a single wavelength. In other words, the wavelength becomes a characteristic of the link itself.

Nevertheless the procedure to light up the fiber may vary depending on the implementation. Since the implementation is unknown a priori, different sequences to light up a wavelength need to be considered:

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

The preferred way to address these in a Control Plane enabled network is neighbour discovery including exchange of link characteristics and link property correlation. The general mechanisms are covered in RFC

4209 [RFC4209] and RFC 4204 [RFC4204] which provides the necessary protocol framework to exchange those characteristics between client and Black Link. LMP-WDM is not intended for exchanging routing or signaling information nor to provision the lambda in the transceiver but covers:

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

Extensions to LMP covering the parameter sets (e.g. application codes) are needed, see draft-ietf-ccamp-dwdm-if-lmp. Additionally, when client and server side are managed by different operational entities, the link state may be useful to help the management system to do troubleshooting or alarm correlation.

#### 4.2.1. Considerations Using GMPLS Signaling

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

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

- a. Using RSVP-TE only for the signalling and LMP as described above to exchange information on the configured optical interface within the edge node
- b. RSVP-TE (typically with loose ERO) to transport additional information

- c. Leaking IGP information instead of exchanging this information needed from the optical network to the edge node (UNI will be transformed to a border-peer model, see RFC 5146 [RFC5146] )

Furthermore following issues should be addressed:

a) The transceivers of peering edge nodes must be compatible. For example, it may be required to know about FEC, modulation scheme, The modulation format, the baudrate and many other parameters described in the drafts reported in the Annex. Depending on where the information is available, compatibility check may either happen before signaling, when the signaling reaches the optical network (e.g. at path computation time), or in the tail end node. An extended version of LMP is needed to exchange this information in case a. above, and to RSVP-TE as well in b. It would be helpful to define some common profiles that will be supported (e.g. the "application identifier") to summarize interface capabilities: if both profiles match, signaling can succeed and provisioning be achieved.

b) Due to the bidirectional wavelength path that must be setup, the upstream edge node must include a wavelength value into the RSVP-TE Path message. But in the case of a UNI model the client device may not have full information about which wavelength must/should be selected, whereas this information must be exchanged between the edge and the core node. The special value defined in [Network-Assigned-Upstream-Label] allows the optical network to assign the actual wavelength to be used by the upstream transponder, which is a simple and efficient solution to this issue.

## 5. Requirements

As network architectures become more complex, management and operations, including the the provisioning process, need progress towards automation. Simplifying and automating the entire management as well as the network provisioning process while enabling higher link utilization and faster restoration times are the main targets of this section.

Supporting network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040] is the base for the communication among EMS/NMS, centralized controller and network elements. This implies to specify the corresponding IETF YANG modules to fully and consistently manage the feature discussed on this document.

Data plane interoperability as defined for example in [ITU-T.G.698.2] is a precondition to take full benefit from standardized interfaces between network and control/management plane.

The following requirements are focusing on the usage of DWDM interfaces using IETF technologies. Obviously, a common set of solutions must be consistently supported by both the devices hosting DWDM interfaces and the WDM network (i.e., the WDM line). The solutions addressing the following requirements will be discussed in further documents.

- 1 A YANG data model MUST define the optical parameters to be exchanged (e.g., power setting) between the network elements and the management plane so as to configure single channel interfaces through NETCONF/RESTCONF.
  - 2 LMP MUST allow to convey the relevant optical parameters between two nodes to correlate neighbor characteristics and identify common capabilities or compatible ranges between the WDM line and single channel interfaces.
  - 3 RSVP-TE MUST support the relevant parameters to be exchanged between the device hosting the DWDM interface and the optical node (e.g. the label value), without preventing the network to remain in charge of the optical path computation.
  - 4 Power monitoring functions at both ends of the DWDM connection MAY be used to further automate the setup and shutdown process of the optical interfaces. LMP SHOULD support a way to carry associated measurement from the client devices to the edges of the WDM network.
  - 5 In fault cases, the network SHOULD be able to recover wavelengths. RSVP-TE extensions MUST remain compatible with [RFC4873] features. The Yang modules should mimic a similar level of capability.
6. Gap Analysis

To enable a centralized control function, several gaps in existing RFCs have been identified:

- 1 RFC 8343 defines a generic YANG model for interface management. However, to control DWDM interfaces, an augmentation needs to be defined which allows to configure DWDM specifics such as wavelength or FEC-type.
- 2 RFC 7224 defines iana-if-type YANG modules and needs extension to include DWDM interfaces.
- 3 RFC 4204 defines the Link Management Protocol (LMP) to correlate link properties between two adjacent nodes. Extensions are required to cover the use cases described such as the correlation between a Transponder and a ROADM node.
- 4 RFC 8454 defines an information model for Abstraction and Control of TE Networks (ACTN). However it does not support impairment aware path selection or computation.
- 5 RFC 7823 describes Performance-Based Path Selection for Explicitly Routed Label Switched Paths (LSPs) Using TE Metric Extensions, but does not define Metric extensions suitable for Impairment aware routing in optical transport Networks
- 6 RFC 7471 in turn defines OSPF Traffic Engineering (TE) Metric Extensions covering several use cases but lacks Impairment awareness.
- 7 RFC 6163 provides a Framework for GMPLS and Path Computation Element (PCE) Control of Wavelength Switched Optical Networks (WSONs). While it describes methods for communicating RWA relevant information, it does not identify such information.
- 8 Yang Models describing the optical parameter to be used to control the network and allow an external controller (like ACTN) to be missing although they are defined by ITU and reported in the

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

Concerning the access control to Management interfaces, security issues can be generally addressed by authentication techniques providing origin verification, integrity and confidentiality. Additionally, access to Management interfaces can be physically or logically isolated, by configuring them to be only accessible out-of-band, through a system that is physically or logically separated from the rest of the network infrastructure. In case where management

interfaces are accessible in-band at the client device or within the optical transport network domain, filtering or firewalling techniques can be used to restrict unauthorized in-band traffic. Authentication techniques may be additionally used in all cases.

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## Appendix A. Use Cases

A comparison with the traditional operation scenarios provides an insight of similarities and distinctions in operation and management of DWDM interfaces. The following use cases provide an overview about operation and maintenance processes.

### A.1. Optical interface parameter collection

It is necessary to identify the Optical interface characteristics and setting in order to properly calculate the end to end path and match the Head End interface against the Tail End interface compatibility. The optical parameters may have multiple possible values that the Controller (SDN or GMPLS) can use and select for the best network optimisation.

### A.2. DWDM client - ROADM interconnection discovery

Being the the DWDM port and ROADM port belonging to different domains and Network Elements, the interconnection between them is not embedded in the Optical Nodes and can not be shared to the EMS and the Controller. The Controller needs then to retrieve the connectivity using data coming from the two domains correlating them to discover the relationship. The methods to discover the interconnection can be LMP, LLDP, installation provisioning or any other mechanism checking using the light transmitted by the DWDM transmitter and detector by the ROADM port photodiode. This use case is fundamental to build the interconnections between the DWDM and Client layer (e.g. Routers) and calculate the multilayer network topology.

### A.3. Service Setup

It is necessary to differentiate between different operational issues for setting up a light path (a DWDM connection is specific in having defined maximum impairments) within an operational network.

The first step is to determine if transceivers located at different end-points are interoperable, i.e. support a common set of operational parameters. In this step it is required to determine transceiver capabilities in a way to be able to correlate them for interoperability purposes. Such parameters include modulation scheme, modulation parameters, FEC to name a few. If both transceivers are controlled by the same NMS or CP, such data is readily available. However in cases like Figure 4, a protocol needs to be used to inform the controlling instance (NMS or CP) about transceiver parameters. It is suggested to extend LMP for that purpose.

The second step is to determine the feasibility of a lightpath between two transceivers without applying an optical signal. Understanding the limitations of the transceiver pair, a path through the optical network has to be found, whereby each path has an individual set of impairments deteriorating a wavelength traveling along that path. Since a single transceiver can support multiple parameter sets, the selection of a path may limit the permissible parameter sets determined in previous steps.

The third step is then to setup the connection itself and to determine the Wavelength. This is done using the NMS of the optical transport network or by means of a control plane interaction such as signaling and includes the path information as well as the parameter set information necessary to enable communication.

In a fourth step, optical monitoring is activated in the WDM network in order to monitor the status of the connection. The monitor functions of the optical interfaces at the terminals are also activated in order to monitor the end to end connection.

Furthermore it should be possible to automate this step. After connecting the client device to the neighbor control plane-enabled transport node, a control adjacency may be automatically established, e.g. using LMP.

#### A.4. Link Monitoring Use Cases

The use cases described below are assuming that power monitoring functions are available in the ingress and egress network element of the DWDM network, respectively. By performing link property correlation it would be beneficial to include the current transmit power value at reference point Ss and the current received power value at reference point Rs. For example if the Client transmitter power has a value of 0dBm and the ROADM interface measured power is -6dBm the fiber patch cord connecting the two nodes may be pinched or the connectors are dirty. As discussed before, the actual path or selection of a specific wavelength within the allowed set is outside the scope of LMP. The computing entities (e.g. the first optical node originating the circuit) can rely on GMPLS IGP (OSPF) to retrieve all the information related to the network, calculate the path to reach the endpoint and signal the path implementation through the network via RSVP-TE.

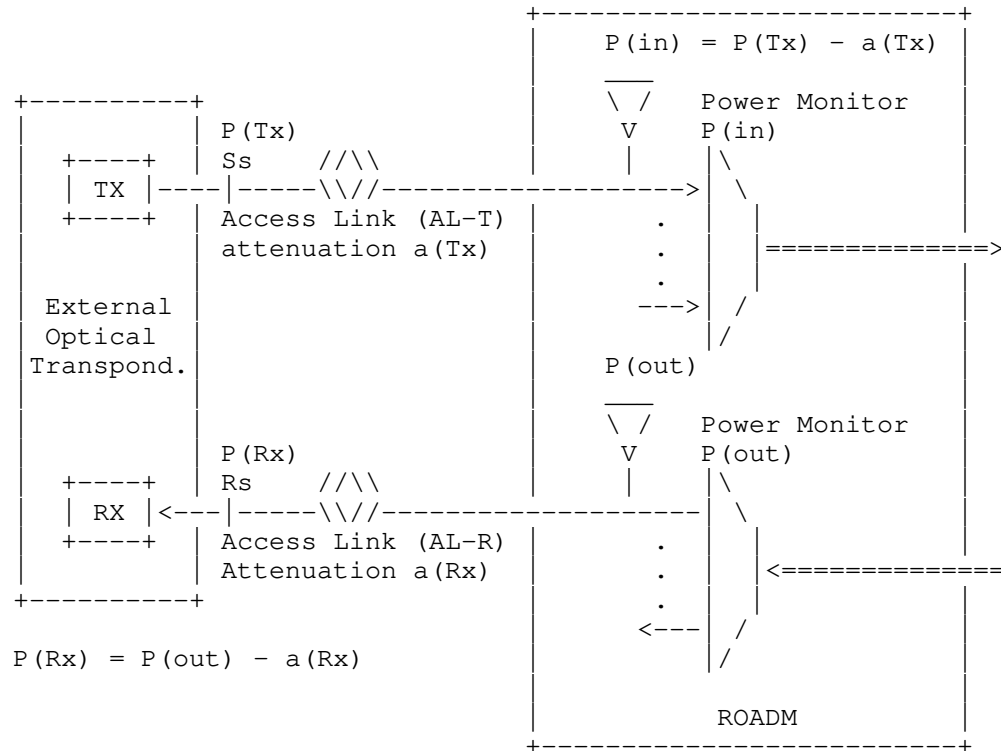
[ITU-T.G.698.2] defines a single channel optical interface for DWDM systems that allows interconnecting network-external optical transponders across a DWDM network. The optical transponders are external to the DWDM network. This so-called 'Black Link' approach illustrated in Fig. 5-1 of [ITU-T.G.698.2] and a copy of this figure

is provided below in Figure 5. The single channel fiber link between the Ss/Rs reference points and the ingress/egress port of the network element on the domain boundary of the DWDM network (DWDM border NE) is called access link. Based on the definition in [ITU-T.G.698.2] it is part of the DWDM network. The access link is typically realized as a passive fiber link that has a specific optical attenuation (insertion loss). As the access link is an integral part of the DWDM network, it is desirable to monitor its attenuation. Therefore, it is useful to detect an increase of the access link attenuation, for example, when the access link fiber has been disconnected and reconnected (maintenance) and a bad patch panel connection (connector) resulted in a significantly higher access link attenuation (loss of signal in the extreme case of an open connector or a fiber cut). In the following section, two use cases are presented and discussed:

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

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

## Use case 1: Access Link monitoring



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

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

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

Alarms and events can be shared between Client and Network via LMP.

Figure 5: Access Link Power Monitoring

## A.4.1. Pure Access Link (AL) Monitoring Use Case

Figure 6 illustrates the access link monitoring use case and the different physical properties involved that are defined below:

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

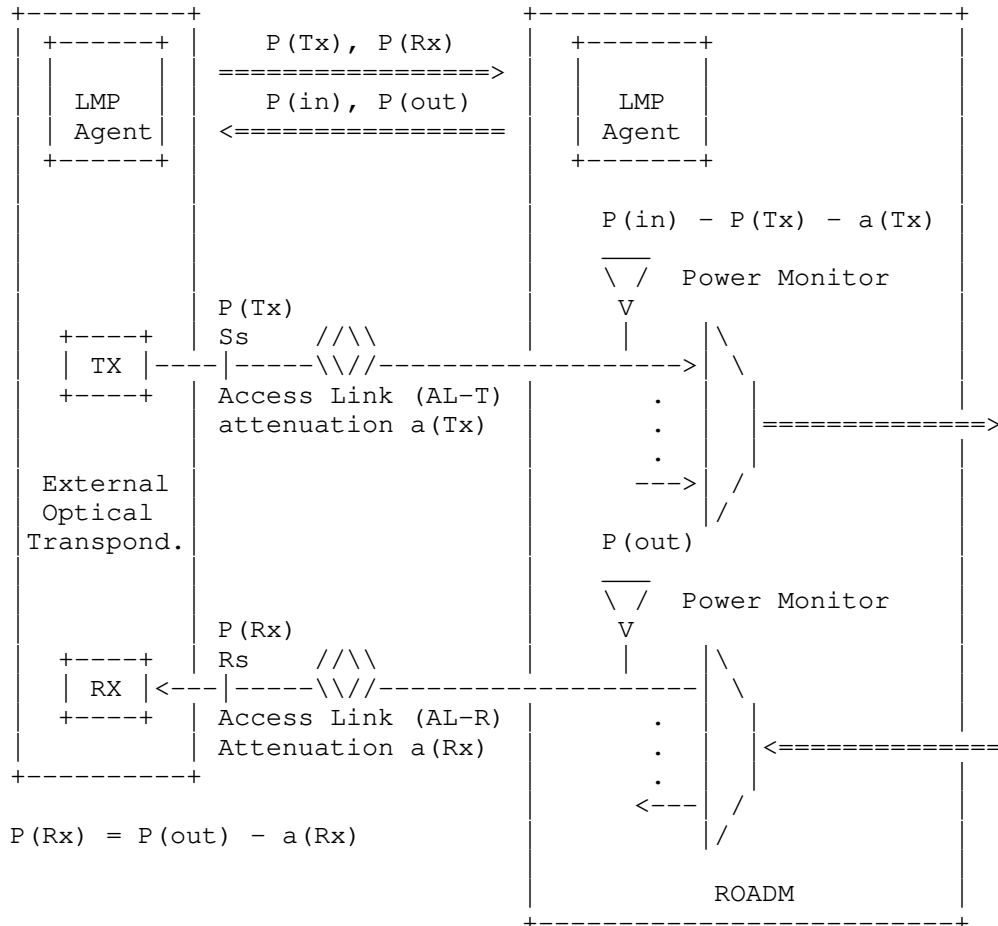
## Description:

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

## Access Link monitoring process:

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

## Use case 2: Access Link monitoring through LMP



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

Alarms and events can be shared between Client and Network via LMP according to [RFC4204] and [RFC4209]

Figure 6: Extended LMP Model

## A.4.2. Power Control Loop Use Case

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

From a data plane perspective, this use case does not require additional data plane extensions. It does only require a protocol extension in the control plane (e.g. this LMP draft) that allows the power control application residing in the DWDM border NE to modify the optical output power of the DWDM domain-external transmitter Tx within the range of the currently used application code. Figure 7 below illustrates this use case utilizing LMP with the extensions identified in this document.

## Use case 3: Power Control Loop

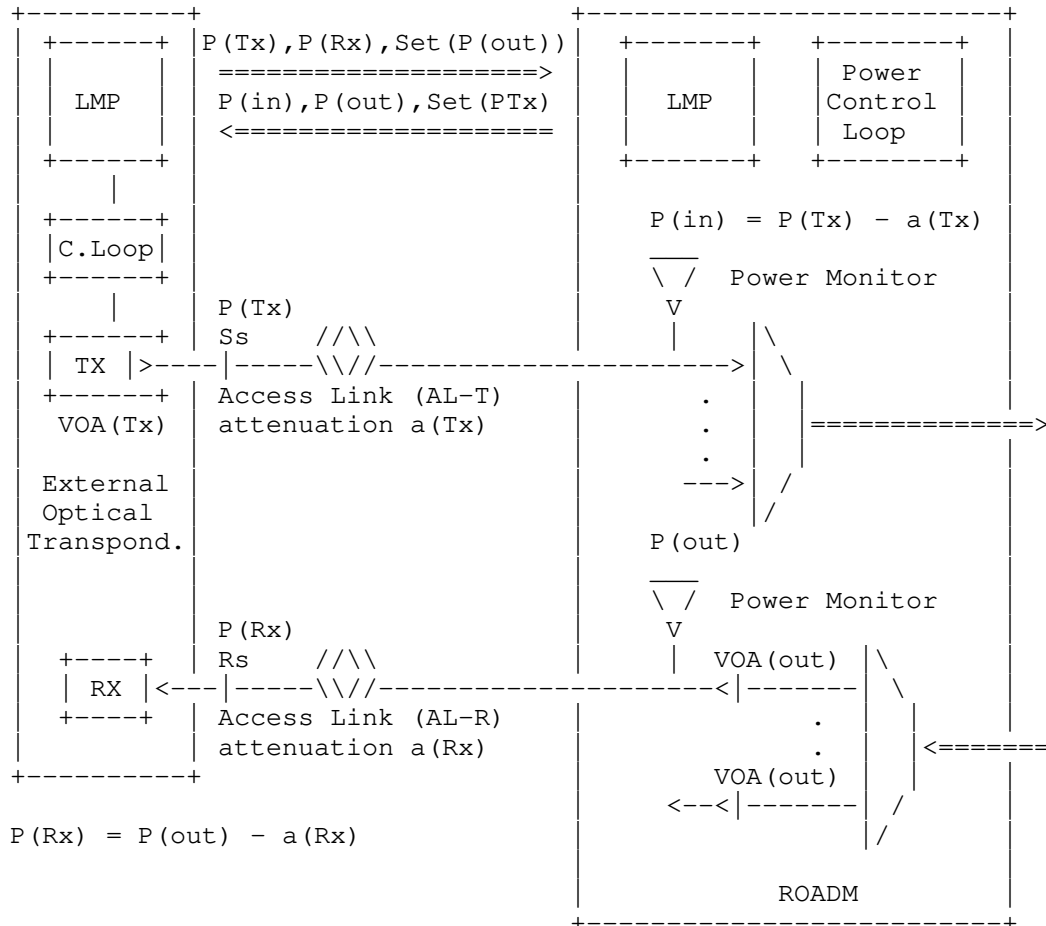


Figure 7: Power control loop

- The power control loop in transponders and ROADMs controls the Variable Optical Attenuators (VOA) to adjust the proper power in base of the ROADM and Receiver characteristics and the Access Link attenuation



#### A.5. Optical Circuit restoration

Upon an network failure (e.g. fiber cut) the Controller or GMPLS can initiate an Optical Path restoration process. Other than reroute the optical path the controller may need to retune the wavelength and modify the DWDM Transceiver working parameters (e.g. FEC, Modulation Format, etc.). This operation is done in realtime and can benefit of Netconf/Yang interface or RSVP signalling on the UNI interface.

#### A.6. Multilayer restoration

A network failure can be due to an DWDM port failure. The Controller is the only actor able to fix issue setting a new circuit terminated on a good Client port (GMPLS is not able to make an new path choosing a different end-point). Other than reroute the optical path the controller may need to provision the wavelength and modify the DWDM Transceiver working parameters (e.g. FEC, Modulation Format, etc.). This operation is done in realtime and must be supported by Netconf/Yang interface.

#### Appendix B. Detailed info drafts

In this section are reported some examples and references on the MIB, Yang and LMP usage. The MIB and TLV defining the parameters described above are reported in the drafts below and are intended as informative data:

**draft-ietf-ccamp-dwdm-if-lmp**

Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage the application code of optical interface parameters in DWDM application

**draft-ggalimbe-ccamp-flex-if-lmp**

Extension to the Link Management Protocol (LMP/DWDM -rfc4209) for Dense Wavelength Division Multiplexing (DWDM) Optical Line Systems to manage the application code of optical interface parameters in DWDM application

**draft-ietf-ccamp-dwdm-if-param-yang**

A YANG model to manage the optical interface parameters for an external transponder in a WDM network

**draft-ietf-ccamp-flexigrid-yang**

YANG data model for Flexi-Grid Optical Networks

**draft-ietf-ccamp-wson-iv-info**

Information Model for Wavelength Switched Optical Networks (WSOs) with Impairments Validation

**draft-ietf-ccamp-wson-iv-encode**

Information Encoding for WSON with Impairments Validation

**draft-galimbe-ccamp-iv-yang**

A YANG model to manage the optical parameters for in a WDM network

NOTE: the above information is defined at the time of publication of this document and thus subject to change.

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A framework for Management and Control of microwave and  
millimeter wave interface parameters  
draft-ietf-ccamp-microwave-framework-01

Abstract

To ensure an efficient data transport, meeting the requirements requested by today's transport services, the unification of control and management of microwave and millimeter wave radio link interfaces is a precondition for seamless multilayer networking and automated network wide provisioning and operation.

This document describes the required characteristics and use cases for control and management of radio link interface parameters using a YANG Data Model. It focuses on the benefits of a standardized management model that is aligned with how other packet technology interfaces in a microwave/millimeter wave node are modeled, the need to support core parameters and at the same time allow for optional product/feature specific parameters supporting new, unique innovative features until they have become mature enough to be included in the standardized model.

The purpose is to create a framework for identification of the necessary information elements and definition of a YANG Data Model for control and management of the radio link interfaces in a microwave/millimeter wave node.

## Status of This Memo

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## 1. Terminology and Definitions

Microwave is a band of spectrum with wavelengths ranging from 1 meter to 1 millimeter and with frequencies ranging between 300 MHz and 300 GHz. Microwave radio technology is widely used for point-to-point telecommunications because of their small wavelength that allows conveniently-sized antennas to direct them in narrow beams, and their comparatively higher frequencies that allows broad bandwidth and high data transmission rates.

Millimeter wave is also known as extremely high frequency (EHF) or very high frequency (VHF) by the International Telecommunications Union (ITU), which can be used for high-speed wireless broadband communications. Millimeter wave can be used for a broad range of fixed and mobile services including high-speed, point-to-point wireless local area networks (WLANs) and broadband access. This band has short wavelengths that range from 10 millimeters to 1 millimeter, namely millimeter band or millimeter wave. The 71 - 76 GHz, 81 - 86 GHz and 92-95 GHz bands are used for point-to-point high-bandwidth communication links, which allows for higher data rates up to 10 Gbit/s but requires a license. Unlicensed short-range data links can be used on 60 GHz millimeter wave. For instance, the upcoming IEEE Wi-Fi standard 802.11ad will run on the 60 GHz spectrum with data transfer rates of up to 7 Gbit/s.

ETSI EN 302 217 series defines the characteristics and requirements of microwave/millimeter wave equipment and antennas. Especially ETSI EN 302 217-2 specifies the essential parameters for the systems operating from 1.4GHz to 86GHz.

Carrier Termination and Radio Link Terminal are two concepts defined to support modeling of microwave radio link features and parameters in a structured and yet simple manner.

Carrier Termination is an interface for the capacity provided over the air by a single carrier. It is typically defined by its transmitting and receiving frequencies.

Radio Link Terminal is an interface providing packet capacity and/or TDM capacity to the associated Ethernet and/or TDM interfaces in a node and used for setting up a transport service over a microwave/millimeter wave link.

Figure 1 provides a graphical representation of Carrier Termination and Radio Link Terminal concepts.

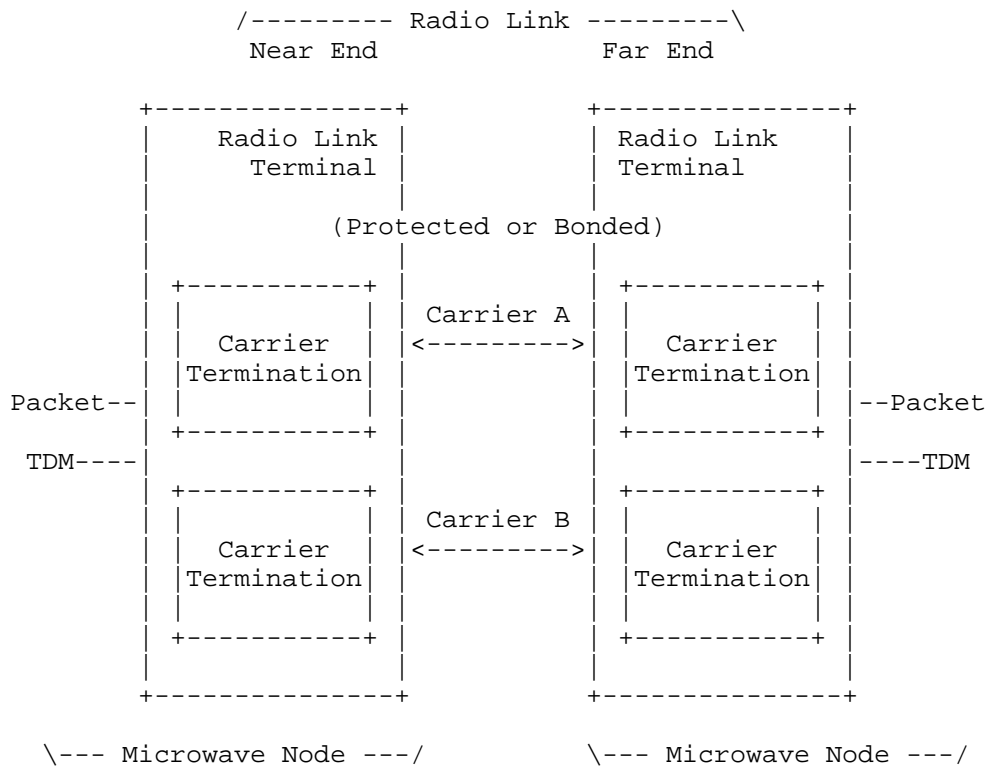


Figure 1. Radio Link Terminal and Carrier Termination

Software Defined Networking (SDN) is an emerging architecture that decouples the network control and forwarding functions enabling the network control to become directly programmable and the underlying infrastructure to be abstracted for applications and network services. This results in an extremely dynamic, manageable, cost-effective, and adaptable architecture that gives administrators unprecedented programmability, automation, and control. The SDN concept is widely applied for network management, the adoption of SDN framework to manage and control the microwave and millimeter wave interface is one of the key applications of this work.

## 2. Introduction

Network requirements vary between operators globally as well as within individual countries. The overall goal is however the same - to deliver the best possible network performance and quality of experience in a cost-efficient way.

Microwave/millimeter wave (hereafter referred to as microwave, but including the frequency bands represented by millimeter wave) are important technologies to fulfill this goal today, but also in the future when demands on capacity and packet features increases.



Microwave is already today able to fully support the capacity needs of a backhaul in a radio access network and will evolve to support multiple gigabits in traditional frequency bands and beyond 10 gigabits in the millimeter wave. L2 packet features are normally an integrated part of microwave nodes and more advanced L2 & L3 features will over time be introduced to support the evolution of the transport services to be provided by a backhaul/transport network. Note that the wireless access technologies such as 3/4/5G & Wi-Fi are not within the scope of this microwave model work.

The main application for microwave is backhaul for mobile broadband. Those networks will continue to be modernized using a combination of microwave and fiber technologies. The choice of technology is a question about fiber presence and cost of ownership, not about capacity limitations in microwave.

Open and standardized interfaces are a pre-requisite for efficient management of equipment from multiple vendors, integrated in a single system/controller. This framework addresses management and control of the radio link interface(s) and the relationship to other packet interfaces, typically to Ethernet interfaces, in a microwave node. A radio link provides the transport over the air, using one or several carriers in aggregated or protected configurations. Managing and controlling a transport service over a microwave node involves both radio link and packet functionality.

Already today there are numerous IETF data models, RFCs and drafts, with technology specific extensions that cover a large part of the packet domain. Examples are IP Management [RFC7277], Routing Management [RFC8022] and Provider Bridge [PB-YANG]. They are based on RFC 7223 [RFC7223], which is the IETF YANG model for Interface Management, and is an evolution of the SNMP IF-MIB [RFC2863].

Since microwave nodes will contain more and more packet functionality which is expected to be managed using those models, there are advantages if radio link interfaces can be modeled and be managed using the same structure and the same approach, specifically for use cases in which a microwave node is managed as one common entity including both the radio link and the packet functionality, e.g. at basic configuration of node & connections, centralized trouble shooting, upgrade and maintenance. All interfaces in a node, irrespective of technology, would then be accessed from the same core model, i.e. RFC 7223, and could be extended with technology specific parameters in models augmenting that core model. The relationship/connectivity between interfaces could be given by the physical equipment configuration, e.g. the slot in which the Radio Link Terminal (modem) is plugged in could be associated with a specific Ethernet port due to the wiring in the backplane of the system, or it could be flexible and therefore configured via a management system or controller.

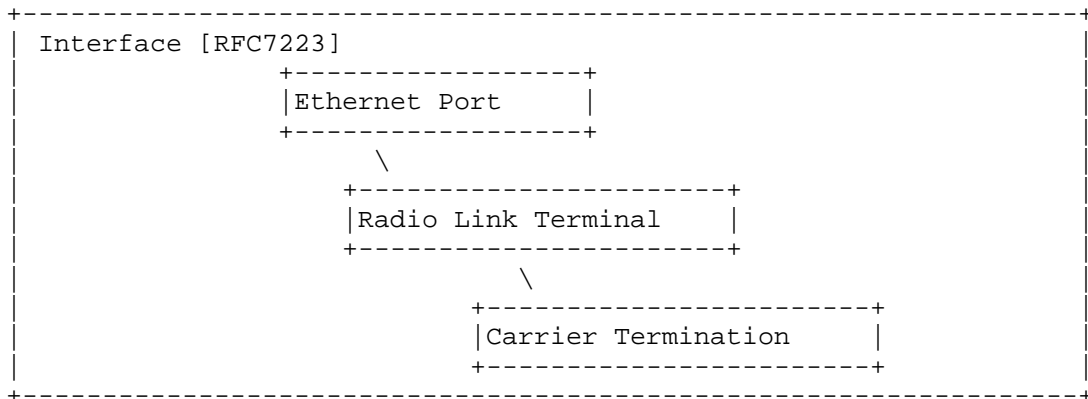


Figure 2: Relationship between interfaces in a node

There will always be certain implementations that differ among products and it is therefore practically impossible to achieve industry consensus on every design detail. It is therefore important to focus on the parameters that are required to support the use cases applicable for centralized, unified, multi-vendor management and to allow other parameters to be optional or to be covered by extensions to the standardized model. Furthermore, a standard that allows for a certain degree of freedom encourages innovation and competition which is something that benefits the entire industry. It is therefore important that a radio link management model covers all relevant functions but also leaves room for product/feature-specific extensions.

For microwave radio link functionality work has been initiated (ONF: Microwave Modeling [ONF-model], IETF: Radio Link Model [I-D.ahlbergccamp-microwave-radio-link]). The purpose of this effort is to reach consensus within the industry around one common approach, with respect to the use cases and requirements to be supported, the type and structure of the model and the resulting attributes to be included. This document describes the use cases and requirements agreed to be covered, the expected characteristics of the model and at the end includes an analysis of how the models in the two on-going initiatives fulfill these expectations and a recommendation on what can be reused and what gaps need to be filled by a new and evolved radio link model.

### 3. Conventions used in this document

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

While [RFC2119] describes interpretations of these key words in terms of protocol specifications and implementations, they are used in this document to describe requirements for the YANG Data Model for Microwave Radio Link.

#### 4. Approaches to manage and control radio link interfaces

This framework addresses the definition of an open and standardized interface for the radio link functionality in a microwave/millimeter wave node. The application of such an interface used for management and control of nodes and networks typically vary from one operator to another, in terms of the systems used and how they interact. A traditional solution is network management system, while an emerging one is SDN. SDN solutions can be used as part of the network management system, allowing for direct network programmability and automated configurability by means of a centralized SDN control and defining standardized interfaces to program the nodes.

##### 4.1. Network Management Solutions

The classic network management solutions, with vendor specific domain management combined with cross domain functionality for service management and analytics, still dominates the market. These solutions are expected to evolve and benefit from an increased focus on standardization by simplifying multi-vendor management and remove the need for vendor/domain specific management.

##### 4.2. Software Defined Networking

One of the main drivers for applying SDN from an operator perspective is simplification and automation of network provisioning as well as E2E network service management. The vision is to have a global view of the network conditions spanning across different vendors' equipment and multiple technologies.

If nodes from different vendors shall be managed by the same SDN controller via a node management interface (north bound interface, NBI), without the extra effort of introducing intermediate systems, all nodes must align their node management interfaces. Hence, an open and standardized node management interface are required in a multi-vendor environment. Such standardized interface enables a unified management and configuration of nodes from different vendors by a common set of applications.

On top of SDN applications to configure, manage and control the nodes and their associated transport interfaces including the L2 and L3 packet/Ethernet interfaces as well as the radio interfaces, there are also a large variety of other more advanced SDN applications that can be exploited and/or developed.

A potential flexible approach for the operators is to use SDN in a logical control way to manage the radio links by selecting a predefined operation mode. The operation mode is a set of logical metrics or parameters describing a complete radio link configuration, such as capacity, availability, priority and power consumption.

An example of an operation mode table is shown in Figure 3. Based on its operation policy (e.g., power consumption or traffic priority), the SDN controller selects one operation mode and translates that into the required configuration of the individual parameters for the radio link terminals and the associated carrier terminations.

ID	Description	Capacity	Availability	Priority	Power
1	High capacity	400 Mbps	99.9%	Low	High
2	High availability	100 Mbps	99.999%	High	Low

Figure 3. Example of an operation mode table

An operation mode bundles together the values of a set of different parameters. How each operation mode maps into certain set of attributes is out of scope of this document. Effort on a standardizing operation mode is required to implement a smoothly operator environment.

## 5. Use Cases

The use cases described should be the basis for identification and definition of the parameters to be supported by a YANG Data model for management of radio links, applicable for centralized, unified, multi-vendor management.

Other product specific use cases, addressing e.g. installation, on-site trouble shooting and fault resolution, are outside the scope of this framework. If required, these use cases are expected to be supported by product specific extensions to the standardized model.

### 5.1. Configuration Management

Configuration of a radio link terminal, the constituent carrier terminations and when applicable the relationship to packet/Ethernet and TDM interfaces.

#### 5.1.1. Understand the capabilities & limitations

Exchange of information between a manager and a device about the capabilities supported and specific limitations in the parameter values & enumerations that can be used.

Support for the XPIC (Cross Polarization Interference Cancellation) feature or not and the maximum modulation supported are two examples on information that could be exchanged.

#### 5.1.2. Initial Configuration

Initial configuration of a radio link terminal, enough to establish L1 connectivity over the hop to an associated radio link terminal on a device at far end. It MAY also include configuration of the relationship between a radio link terminal and an associated traffic interface, e.g. an Ethernet interface, unless that is given by the equipment configuration.

Frequency, modulation, coding and output power are examples of parameters typically configured for a carrier termination and type of aggregation/bonding or protection configurations expected for a radio link terminal.

#### 5.1.3. Radio link re-configuration & optimization

Re-configuration, update or optimization of an existing radio link terminal. Output power and modulation for a carrier termination and protection schemas and activation/de-activation of carriers in a radio link terminal are examples on parameters that can be re-configured and used for optimization of the performance of a network.

#### 5.1.4. Radio link logical configuration

Radio link terminals comprising a group of carriers are widely used in microwave technology. There are several kinds of groups: aggregation/bonding, 1+1 protection/redundancy, etc. To avoid configuration on each carrier termination directly, a logical control provides flexible management by mapping a logical configuration to a set of physical attributes. This could also be applied in a hierarchical SDN environment where some domain controllers are located between the SDN controller and the radio link terminal.

### 5.2. Inventory

#### 5.2.1. Retrieve logical inventory & configuration from device

Request from manager and response by device with information about radio interfaces, their constitution and configuration.

#### 5.2.2. Retrieve physical/equipment inventory from device

Request from manager about physical and/or equipment inventory associated with the radio link terminals and carrier terminations.

#### 5.3. Status & statistics

##### 5.3.1. Actual status & performance of a radio link interface

Manager requests and device responds with information about actual status and statistics of configured radio link interfaces and their constituent parts.

#### 5.4. Performance management

##### 5.4.1. Configuration of historical measurements to be performed

Configuration of historical measurements to be performed on a radio link interface and/or its constituent parts is a subset of the configuration use case to be supported. See 5.1 above.

##### 5.4.2. Collection of historical performance data

Collection of historical performance data in bulk by the manager is a general use case for a device and not specific to a radio link interface.

Collection of an individual counter for a specific interval is in same cases required as a complement to the retrieval in bulk as described above.

#### 5.5. Fault Management

##### 5.5.1. Configuration of alarm reporting

Configuration of alarm reporting associated specifically with radio interfaces, e.g. configuration of alarm severity, is a subset of the configuration use case to be supported. See 5.1 above.

##### 5.5.2. Alarm management

Alarm synchronization, visualization & handling, and notifications & events are generic use cases for a device and not specific to a radio link interface and should be supported accordingly.

#### 5.6. Troubleshooting and Root Cause Analysis

Information and actions required by a manager/operator to investigate and understand the underlying issue to a problem in the performance and/or functionality of a radio link terminal and the associated carrier terminations.

## 6. Requirements

For managing a microwave node including both the radio link and the packet functionality, a unified data model is desired to unify the modeling of the radio link interfaces and the packet interfaces using the same structure and the same modelling approach.

The purpose of the YANG Data Model is for management and control of the radio link interface(s) and the relationship/connectivity to other packet interfaces, typically to Ethernet interfaces, in a microwave node.

The capability of configuring and managing microwave nodes includes the following requirements for the modelling:

- 1) It MUST be possible to configure, manage and control a radio link terminal and the constituent carrier terminations.
  - a) Frequency, channel bandwidth, modulation, coding and transmitter power are examples of parameters typically configured for a carrier termination.
  - b) A radio link terminal MUST configure the associated carrier terminations and the type of aggregation/bonding or protection configurations expected for the radio link terminal.
  - c) The capability, e.g. the maximum modulation supported, and the actual status/statistics, e.g. administrative status of the carriers, SHOULD also be supported by the data model.
  - d) The definition of the features and parameters SHOULD be based on established microwave equipment and radio standards, such as ETSI EN 302 217 [EN 302 217-2] which specifies the essential parameters for microwave systems operating from 1.4GHz to 86GHz.
- 2) It MUST be possible to map different traffic types (e.g. TDM, Ethernet) to the transport capacity provided by a specific radio link terminal.
- 3) It MUST be possible to configure and collect historical measurements (for the use case described in section 5.4) to be performed on a radio link interface, e.g. minimum, maximum and average transmit power and receive level in dBm.
- 4) It MUST be possible to configure and retrieve alarms reporting associated with the radio interfaces, e.g. configuration of alarm severity, supported alarms like configuration fault, signal lost, modem fault, radio fault.

## 7. Gap Analysis on Models

The purpose of the gap analysis is to identify and recommend what existing and established models as well as draft models under definition to support the use cases and requirements specified in the previous chapters. It shall also make a recommendation on how the gaps not supported should be filled, including the need for development of new models and evolution of existing models and drafts.

For microwave radio link functionality work has been initiated (ONF: Microwave Modeling [ONF-model], IETF: Radio Link Model [I-D.ahlbergccamp-microwave-radio-link]). The analysis is expected to take these initiatives into consideration and make a recommendation on how to make use of them and how to complement them in order to fill the gaps identified.

For generic functionality, not specific for radio link, the ambition is to refer to existing or emerging models that could be applicable for all functional areas in a microwave node.

### 7.1. Microwave Radio Link Functionality

[ONF CIM] defines a CoreModel of the ONF Common Information Model. An information model describes the things in a domain in terms of objects, their properties (represented as attributes), and their relationships. The ONF information model is expressed in Unified Modeling Language (UML). The ONF CoreModel is independent of specific data plane technology. Data plane technology specific properties are acquired in a runtime solution via "filled in" cases of specification (LtpSpec etc). These can be used to augment the CoreModel to provide a data plane technology specific representation.

IETF Data Model defines an implementation and NETCONF-specific details. YANG is a data modeling language used to model the configuration and state data. It is well aligned with the structure of the Yang data models proposed for the different packet interfaces which are all based on RFC 7223. Furthermore, several YANG data models have been proposed in the IETF for other transport technologies such as optical transport; e.g., RFC 7277 [RFC7277], [I.D.zhang-ccamp-11-topo-yang], [I.D.ietf-ospf-yang]. In light of this trend, the IETF data model is becoming a popular approach for modeling most packet transport technology interfaces and it is thereby well positioned to become an industry standard.



RFC 3444 [RFC3444] explains the difference between Information Model(IM) and Data Models(DM). IM is to model managed objects at a conceptual level for designers and operators, DM is defined at a lower level and includes many details for implementers. In addition, the protocol-specific details are usually included in DM. Since conceptual models can be implemented in different ways, multiple DMs can be derived from a single IM. To ensure better interoperability, it is better to focus on DM directly.

RFC 7223 describes an interface management model, however it doesn't include technology specific information, e.g., for radio interface. [I-D.ahlberg-ccamp-microwave-radio-link] provides a model proposal for radio interfaces, which includes support for basic configuration, status and performance but lacks full support for alarm management and interface layering, i.e. the connectivity of the transported capacity (TDM & Ethernet) with other internal technology specific interfaces in a microwave node.

The recommendation is to use the structure of the IETF: Radio Link Model [I-D.ahlberg-ccamp-microwave-radio-link] as the starting point, since it is a data model providing the wanted alignment with RFC 7223. For the definition of the detailed leaves/parameters, the recommendation is to use the IETF: Radio Link Model and the ONF: Microwave Modeling [ONF-model] as the basis and to define new ones to cover identified gaps. The parameters in those models have been defined by both operators and vendors within the industry and the implementations of the ONF Model have been tested in the Proof of Concept events in multi-vendor environments, showing the validity of the approach proposed in this framework document.

It is also recommended to add the required data nodes to describe the interface layering for the capacity provided by a radio link terminal and the associated Ethernet and TDM interfaces in a microwave node. The principles and data nodes for interface layering described in RFC 7223 should be used as a basis.

## 7.2. Generic Functionality

For generic functionality, not specific for radio link, the recommendation is to refer to existing RFCs or emerging drafts according to the table in figure 4 below. New Radio Link Model is used in the table for the cases where the functionality is recommended to be included in the new radio link model as described in chapter 7.1.

Generic Functionality	Recommendation
1. Fault Management	
Alarm Configuration	New Radio Link Model
Alarm notifications/ synchronization	[I-D.vallin-netmod- alarm-module]
2. Performance Management	
Performance Configuration/ Activation	New Radio Link Model
Performance Collection	New Radio Link Model & XML files
3. Physical/Equipment Inventory	[I-D.ietf-netmod-entity]

Figure 4. Recommendation on how to support generic functionality

Microwave specific alarm configurations are recommended to be included in the new radio link model and could be based on what is supported in the IETF and ONF Radio Link Models. Alarm notifications and synchronization are general and is recommended to be supported by a generic model, such as [I-D.vallin-netmod-alarm-module].

Activation of interval counters & thresholds could be a generic function but it is recommended to be supported by the new radio link specific model and can be based on both the ONF and IETF Microwave Radio Link models.

Collection of interval/historical counters is a generic function that needs to be supported in a node. File based collection via SFTP and collection via a Netconf/YANG interfaces are two possible options and the recommendation is to include support for the latter in the new radio link specific model. The ONF and IETF Microwave Radio Link models can be used as a basis also in this area.

Physical and/or equipment inventory associated with the radio link terminals and carrier terminations is recommended to be covered by a model generic for the complete node, e.g. [I-D.ietf-netmod-entity] and it is thereby outside the scope of the radio link specific model.

### 7.3. Summary

The conclusions and recommendations from the analysis can be summarized as follows:

- 1) A Microwave Radio Link YANG Data Model should be defined with a scope enough to support the use cases and requirements in chapter 5 and 6 of this document.
- 2) Use the structure in the IETF: Radio Link Model [I-D.ahlberg-ccamp-microwave-radio-link] as the starting point. It augments RFC 7223 and is thereby as required aligned with the structure of the models for management of the packet domain.
- 3) Use established microwave equipment and radio standards, such as ETSI EN 302 217 [EN 302 217-2], and the IETF: Radio Link Model [I-D.ahlberg-ccamp-microwave-radio-link] and the ONF: Microwave Modeling [ONF-model] as the basis for the definition of the detailed leaves/parameters to support the specified use cases and requirements, and proposing new ones to cover identified gaps.
- 4) Add the required data nodes to describe the interface layering for the capacity provided by a radio link terminal and the associated Ethernet and TDM interfaces, using the principles and data nodes for interface layering described in RFC 7223 as a basis.
- 5) Include support for configuration of microwave specific alarms in the Microwave Radio Link model and rely on a generic model such as [I.D.vallin-netmod-alarm-module] for notifications and alarm synchronization.
- 6) Use a generic model such as [I-D.ietf-netmod-entity] for physical/equipment inventory.

It is furthermore recommended that the Microwave Radio Link YANG Data Model should be validated by both operators and vendors as part of the process to make it stable and mature.

### 8. Security Considerations

TBD

### 9. IANA Considerations

This memo includes no request to IANA.

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A framework for Management and Control of microwave and millimeter wave  
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draft-ietf-ccamp-microwave-framework-07

## Abstract

The unification of control and management of microwave radio link interfaces is a precondition for seamless multilayer networking and automated network provisioning and operation.

This document describes the required characteristics and use cases for control and management of radio link interface parameters using a YANG Data Model.

The purpose is to create a framework for identification of the necessary information elements and definition of a YANG Data Model for control and management of the radio link interfaces in a microwave node. Some parts of the resulting model may be generic which could also be used by other technologies, e.g., Ethernet technology.

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## 1. Introduction

Microwave radio is a technology that uses high frequency radio waves to provide high speed wireless connections that can send and receive voice, video, and data information. It is a general term used for systems covering a very large range of traffic capacities, channel separations, modulation formats and applications over a wide range of frequency bands from 1.4 GHz up to and above 100 GHz.

The main application for microwave is backhaul for mobile broadband. Those networks will continue to be modernized using a combination of microwave and fiber technologies. The choice of technology is a question about fiber presence and cost of ownership, not about capacity limitations in microwave.

Microwave is already today able to fully support the capacity needs of a backhaul in a radio access network and will evolve to support multiple gigabits in traditional frequency bands and beyond 10 gigabits in higher frequency bands with more bandwidth. L2 Ethernet features are normally an integrated part of microwave nodes and more advanced L2 and L3 features will over time be introduced to support the evolution of the transport services to be provided by a backhaul/transport network. Note that the wireless access technologies such as 3/4/5G and Wi-Fi are not within the scope of this microwave model work.

Open and standardized interfaces are a pre-requisite for efficient management of equipment from multiple vendors, integrated in a single system/controller. This framework addresses management and control of the radio link interface(s) and the relationship to other interfaces, typically to Ethernet interfaces, in a microwave node. A radio link provides the transport over the air, using one or several carriers in aggregated or protected configurations. Managing and controlling a transport service over a microwave node involves both radio link and packet transport functionality.

Already today there are numerous IETF data models, RFCs and drafts, with technology specific extensions that cover a large part of the L2 and L3 domains. Examples are IP Management [RFC8344], Routing Management [RFC8349] and Provider Bridge [PB-YANG]. They are based on the IETF YANG model for Interface Management [RFC8343], which is an evolution of the SNMP IF-MIB [RFC2863].

Since microwave nodes will contain more and more L2 and L3(packet) functionality which is expected to be managed using those models, there are advantages if radio link interfaces can be modeled and managed using the same structure and the same approach, specifically for use cases in which a microwave node is managed as one common

entity including both the radio link and the L2 and L3 functionality, e.g. at basic configuration of node and connections, centralized trouble shooting, upgrade and maintenance. All interfaces in a node, irrespective of technology, would then be accessed from the same core model, i.e. [RFC8343], and could be extended with technology specific parameters in models augmenting that core model. The relationship/ connectivity between interfaces could be given by the physical equipment configuration, e.g. the slot in which the Radio Link Terminal (modem) is plugged in could be associated with a specific Ethernet port due to the wiring in the backplane of the system, or it could be flexible and therefore configured via a management system or controller.

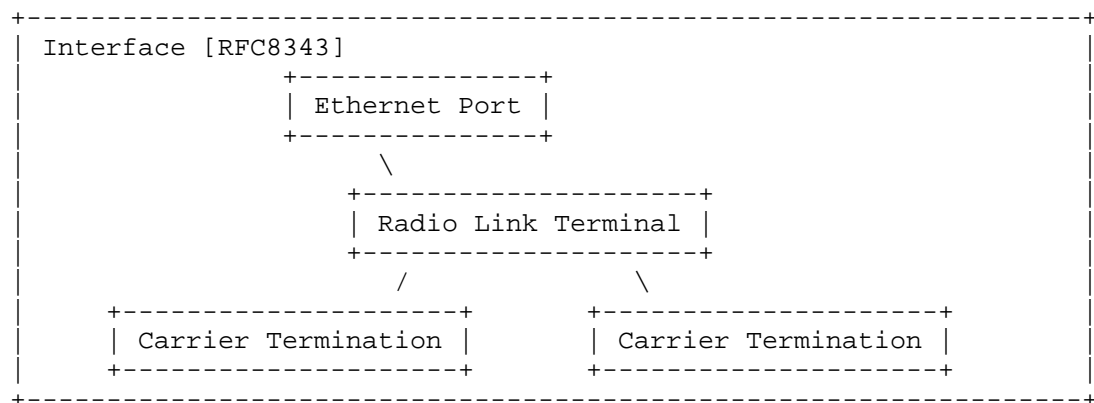


Figure 1: Relationship between interfaces in a node

There will always be certain implementations that differ among products and it is therefore practically impossible to achieve industry consensus on every design detail. It is therefore important to focus on the parameters that are required to support the use cases applicable for centralized, unified, multi-vendor management and to allow other parameters to be optional or to be covered by extensions to the standardized model. Furthermore, a standard that allows for a certain degree of freedom encourages innovation and competition which is something that benefits the entire industry. It is therefore important that a radio link management model covers all relevant functions but also leaves room for product/feature-specific extensions.

For microwave radio link functionality work has been initiated (ONF: Microwave Modeling [ONF-model], IETF: Radio Link Model [I-D.ietf-ccamp-mw-yang]). The purpose of this effort is to reach consensus within the industry around one common approach, with respect to the use cases and requirements to be supported, the type

and structure of the model and the resulting attributes to be included. This document describes the use cases and requirements agreed to be covered, the expected characteristics of the model and at the end includes an analysis of how the models in the two on-going initiatives fulfill these expectations and a recommendation on what can be reused and what gaps need to be filled by a new and evolved radio link model.

### 1.1. Conventions used in this document

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

## 2. Terminology and Definitions

Microwave radio is a term commonly used for technologies that operate in both microwave and millimeter wave lengths and in frequency bands from 1.4 GHz up to and beyond 100 GHz. In traditional bands it typically supports capacities of 1-3 Gbps and in 70/80 GHz band up to 10 Gbps. Using multi-carrier systems operating in frequency bands with wider channels, the technology will be capable of providing capacities of up to 100 Gbps.

The microwave radio technology is widely used for point-to-point telecommunications because of its small wavelength that allows conveniently-sized antennas to direct them in narrow beams, and the comparatively higher frequencies that allow broad bandwidth and high data transmission rates. It is used for a broad range of fixed and mobile services including high-speed, point-to-point wireless local area networks (WLANs) and broadband access.

ETSI EN 302 217 series defines the characteristics and requirements of microwave equipment and antennas. Especially ETSI EN 302 217-2 [EN302217-2] specifies the essential parameters for the systems operating from 1.4GHz to 86GHz.

Carrier Termination and Radio Link Terminal are two concepts defined to support modeling of microwave radio link features and parameters in a structured and yet simple manner.

Carrier Termination is an interface for the capacity provided over the air by a single carrier. It is typically defined by its transmitting and receiving frequencies.

Radio Link Terminal is an interface providing Ethernet capacity and/or Time Division Multiplexing (TDM) capacity to the associated

Ethernet and/or TDM interfaces in a node and used for setting up a transport service over a microwave radio link.

Figure 2 provides a graphical representation of Carrier Termination and Radio Link Terminal concepts.

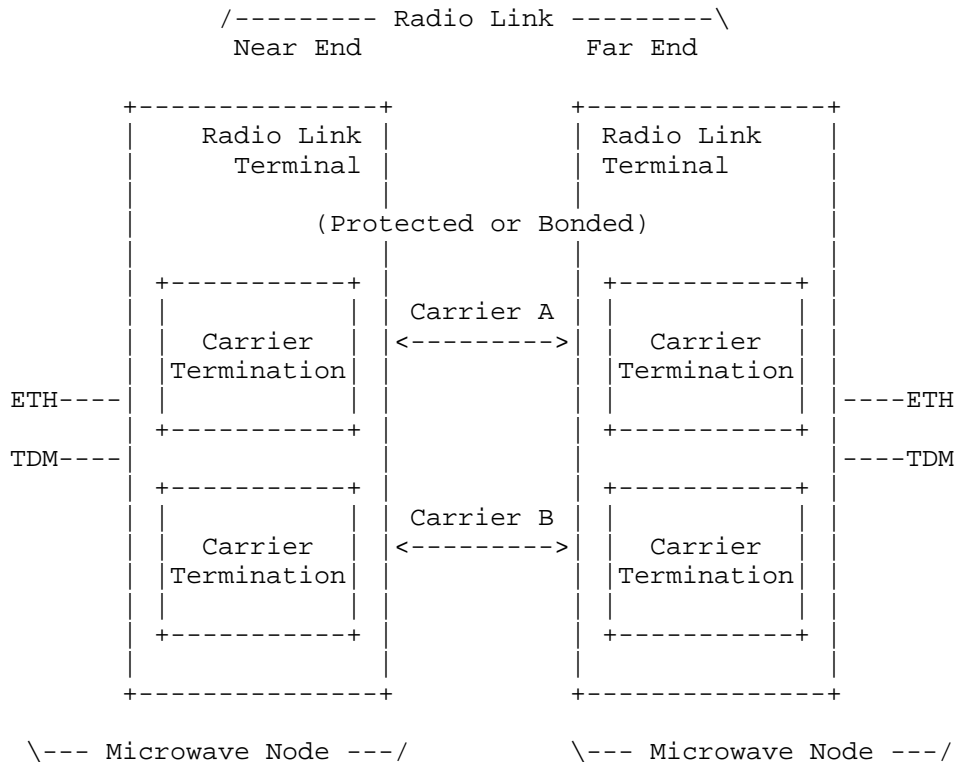


Figure 2: Radio Link Terminal and Carrier Termination

Software Defined Networking (SDN) is an architecture that decouples the network control and forwarding functions enabling the network control to become directly programmable and the underlying infrastructure to be abstracted for applications and network services. SDN can be used for automation of traditional network management functionality using an SDN approach of standardized programmable interfaces for control and management [RFC7426].

### 3. Approaches to manage and control radio link interfaces

This framework addresses the definition of an open and standardized interface for the radio link functionality in a microwave node. The application of such an interface used for management and control of

nodes and networks typically vary from one operator to another, in terms of the systems used and how they interact. Possible approaches include via the use of a network management system (NMS), via software defined networking (SDN) and via some combination of NMS and SDN. As there are still many networks where the NMS is implemented as one component/interface and the SDN controller is scoped to control plane functionality as a separate component/interface, this document does not preclude either model. The aim of this document is to provide a framework for development of a common YANG Data Model for both management and control of microwave interfaces.

### 3.1. Network Management Solutions

The classic network management solutions, with vendor specific domain management combined with cross domain functionality for service management and analytics, still dominate the market. These solutions are expected to evolve and benefit from an increased focus on standardization by simplifying multi-vendor management and remove the need for vendor/domain specific management.

### 3.2. Software Defined Networking

One of the main drivers for applying SDN from an operator perspective is simplification and automation of network provisioning as well as end to end network service management. The vision is to have a global view of the network conditions spanning across different vendors' equipment and multiple technologies.

If nodes from different vendors are to be managed by the same SDN controller via a node management interface (north bound interface, NBI), without the extra effort of introducing intermediate systems, all nodes must align their node management interfaces. Hence, an open and standardized node management interface is required in a multi-vendor environment. Such a standardized interface enables a unified management and configuration of nodes from different vendors by a common set of applications.

On top of SDN applications to configure, manage and control the nodes and their associated transport interfaces including the L2 Ethernet and L3 IP interfaces as well as the radio interfaces, there are also a large variety of other more advanced SDN applications that can be utilized and/or developed.

A potentially flexible approach for the operators is to use SDN in a logical control way to manage the radio links by selecting a predefined operation mode. The operation mode is a set of logical metrics or parameters describing a complete radio link configuration, such as capacity, availability, priority and power consumption.

An example of an operation mode table is shown in Figure 3. Based on its operation policy (e.g., power consumption or traffic priority), the SDN controller selects one operation mode and translates that into the required configuration of the individual parameters for the radio link terminals and the associated carrier terminations.

ID	Description	Capacity	Availability	Priority	Power
1	High capacity	400 Mbps	99.9%	Low	High
2	High availability	100 Mbps	99.999%	High	Low

Figure 3: Example of an operation mode table

An operation mode bundles together the values of a set of different parameters. How each operation mode maps into certain set of attributes is out of scope of this document.

#### 4. Use Cases

The use cases described should be the basis for identification and definition of the parameters to be supported by a YANG Data model for management of radio links, applicable for centralized, unified, multi-vendor management. The use cases involve configuration management, inventory, status and statistics, performance management, fault management, troubleshooting and root cause analysis.

Other product specific use cases, addressing e.g. installation, on-site trouble shooting and fault resolution, are outside the scope of this framework. If required, these use cases are expected to be supported by product specific extensions to the standardized model.

##### 4.1. Configuration Management

Configuration of a radio link terminal, the constituent carrier terminations and when applicable the relationship to IP/Ethernet and TDM interfaces.

- o Understand the capabilities and limitations

Exchange of information between a manager and a device about the capabilities supported and specific limitations in the parameter values and enumerations that can be used.

Support for the XPIC (Cross Polarization Interference Cancellation) feature or not and the maximum modulation supported are two examples on information that could be exchanged.

- o Initial Configuration

Initial configuration of a radio link terminal, enough to establish L1 connectivity to an associated radio link terminal on a device at far end over the hop. It may also include configuration of the relationship between a radio link terminal and an associated traffic interface, e.g. an Ethernet interface, unless that is given by the equipment configuration.

Frequency, modulation, coding and output power are examples of parameters typically configured for a carrier termination and type of aggregation/bonding or protection configurations expected for a radio link terminal.

- o Radio link re-configuration and optimization

Re-configuration, update or optimization of an existing radio link terminal. Output power and modulation for a carrier termination and protection schemas and activation/de-activation of carriers in a radio link terminal are examples on parameters that can be re-configured and used for optimization of the performance of a network.

- o Radio link logical configuration

Radio link terminals configured to include a group of carriers are widely used in microwave technology. There are several kinds of groups: aggregation/bonding, 1+1 protection/redundancy, etc. To avoid configuration on each carrier termination directly, a logical control provides flexible management by mapping a logical configuration to a set of physical attributes. This could also be applied in a hierarchical SDN environment where some domain controllers are located between the SDN controller and the radio link terminal.

#### 4.2. Inventory

- o Retrieve logical inventory and configuration from device

Request from manager and response by device with information about radio interfaces, their constitution and configuration.

- o Retrieve physical/equipment inventory from device



Request from manager about physical and/or equipment inventory associated with the radio link terminals and carrier terminations.

#### 4.3. Status and statistics

- o Actual status and performance of a radio link interface

Manager requests and device responds with information about actual status and statistics of configured radio link interfaces and their constituent parts. It's important to report the effective bandwidth of a radio link since it can be configured to dynamically adjust the modulation based on the current signal conditions.

#### 4.4. Performance management

- o Configuration of historical performance measurements

Configuration of historical performance measurements for a radio link interface and/or its constituent parts. See Section 4.1 above.

- o Collection of historical performance data

Collection of historical performance data in bulk by the manager is a general use case for a device and not specific to a radio link interface.

Collection of an individual counter for a specific interval is in some cases required as a complement to the retrieval in bulk as described above.

#### 4.5. Fault Management

- o Configuration of alarm reporting

Configuration of alarm reporting associated specifically with radio interfaces, e.g. configuration of alarm severity, is a subset of the configuration use case to be supported. See Section 4.1 above.

- o Alarm management

Alarm synchronization, visualization, handling, notifications and events are generic use cases for a device and should be supported on a radio link interface. There are however radio-specific alarms that are important to report, where signal degradation of the radio link is one example.

#### 4.6. Troubleshooting and Root Cause Analysis

Information and actions required by a manager/operator to investigate and understand the underlying issue to a problem in the performance and/or functionality of a radio link terminal and the associated carrier terminations.

#### 5. Requirements

For managing a microwave node including both the radio link and the packet transport functionality, a unified data model is desired to unify the modeling of the radio link interfaces and the L2/L3 interfaces using the same structure and the same modelling approach. If some part of model is generic for other technology usage, it should be clearly stated.

The purpose of the YANG Data Model is for management and control of the radio link interface(s) and the relationship/connectivity to other interfaces, typically to Ethernet interfaces, in a microwave node.

The capability of configuring and managing microwave nodes includes the following requirements for the modelling:

1. It MUST be possible to configure, manage and control a radio link terminal and the constituent carrier terminations.
  - A. Configuration of frequency, channel bandwidth, modulation, coding and transmitter output power MUST be supported for a carrier termination.
  - B. A radio link terminal MUST configure the associated carrier terminations and the type of aggregation/bonding or protection configurations expected for the radio link terminal.
  - C. The capability, e.g. the maximum modulation supported, and the actual status/statistics, e.g. administrative status of the carriers, SHOULD also be supported by the data model.
  - D. The definition of the features and parameters SHOULD be based on established microwave equipment and radio standards, such as ETSI EN 302 217 [EN302217-2] which specifies the essential parameters for microwave systems operating from 1.4GHz to 86GHz.

2. It MUST be possible to map different traffic types (e.g. TDM, Ethernet) to the transport capacity provided by a specific radio link terminal.
3. It MUST be possible to configure and collect historical measurements (for the use case described in section 5.4) to be performed on a radio link interface, e.g. minimum, maximum and average transmit power and receive level in dBm.
4. It MUST be possible to configure and retrieve alarms reporting associated with the radio interfaces, e.g. configuration of alarm severity, supported alarms like configuration fault, signal lost, modem fault, radio fault.

## 6. Gap Analysis on Models

The purpose of the gap analysis is to identify and recommend what models to use in a microwave device to support the use cases and requirements specified in the previous chapters. This draft shall also make a recommendation on how the gaps not supported should be filled, including the need for development of new models and evolution of existing models and drafts.

For microwave radio link functionality work has been initiated (ONF: Microwave Modeling [ONF-model], IETF: Radio Link Model [I-D.ietf-ccamp-mw-yang]). The analysis is expected to take these initiatives into consideration and make a recommendation on how to make use of them and how to complement them in order to fill the gaps identified.

For generic functionality, not specific for radio link, the ambition is to refer to existing or emerging models that could be applicable for all functional areas in a microwave node.

### 6.1. Microwave Radio Link Functionality

[ONF-CIM] defines a CoreModel of the ONF Common Information Model. An information model describes the things in a domain in terms of objects, their properties (represented as attributes), and their relationships. The ONF information model is expressed in Unified Modeling Language (UML). The ONF CoreModel is independent of specific data plane technology. The technology specific content, acquired in a runtime solution via "filled in" cases of specification, augment the CoreModel to provide a forwarding technology-specific representation.

IETF Data Model defines an implementation and protocol-specific details. YANG is a data modeling language used to model the

configuration and state data. [RFC8343] defines a generic YANG data model for interface management which doesn't include technology specific information. To describe the technology specific information, several YANG data models have been proposed in IETF by augmenting [RFC8343], e.g. [RFC8344]. The YANG data model is a popular approach for modeling many packet transport technology interfaces, and it is thereby well positioned to become an industry standard. In light of this trend, [I-D.ietf-ccamp-mw-yang] provides a YANG data model proposal for radio interfaces, which is well aligned with the structure of other technology-specific YANG data models augmenting [RFC8343].

[RFC3444] explains the difference between Information Model(IM) and Data Models(DM). IM is to model managed objects at a conceptual level for designers and operators, while DM is defined at a lower level and includes many details for implementers. In addition, the protocol-specific details are usually included in DM. Since conceptual models can be implemented in different ways, multiple DMs can be derived from a single IM.

It is recommended to use the structure of the IETF: Radio Link Model [I-D.ietf-ccamp-mw-yang] as the starting point, since [I-D.ietf-ccamp-mw-yang] is a data model providing the wanted alignment with [RFC8343]. To cover the identified gaps, it is recommended to define new leafs/parameters in [I-D.ietf-ccamp-mw-yang] while taking reference from [ONF-CIM]. It is also recommended to add the required data nodes to describe the interface layering for the capacity provided by a radio link terminal and the associated Ethernet and TDM interfaces in a microwave node. The principles and data nodes for interface layering described in [RFC8343] should be used as a basis.

## 6.2. Generic Functionality

For generic functionality, not specific for radio link, the recommendation is to refer to existing RFCs or emerging drafts according to the table in Figure 4 below. New Radio Link Model is used in the table for the cases where the functionality is recommended to be included in the new radio link model as described in Section 6.1.

Generic Functionality	Recommendation
1.Fault Management	
Alarm Configuration	New Radio Link Model
Alarm notifications/ synchronization	[I-D.ietf-ccamp- alarm-module]
2.Performance Management	
Performance Configuration/ Activation	New Radio Link Model
Performance Collection	New Radio Link Model and XML files
3.Physical/Equipment Inventory	[RFC8348]

Figure 4: Recommendation on how to support generic functionality

Microwave specific alarm configurations are recommended to be included in the new radio link model and could be based on what is supported in the IETF and ONF Radio Link Models. Alarm notifications and synchronization are general and is recommended to be supported by a generic model, such as [I-D.ietf-ccamp-alarm-module].

Activation of interval counters and thresholds could be a generic function but it is recommended to be supported by the new radio link specific model and can be based on both the ONF and IETF Microwave Radio Link models.

Collection of interval/historical counters is a generic function that needs to be supported in a node. File based collection via SSH File Transfer Protocol(SFTP) and collection via a NETCONF/YANG interfaces are two possible options and the recommendation is to include support for the latter in the new radio link specific model. The ONF and IETF Microwave Radio Link models can be used as a basis also in this area.

Physical and/or equipment inventory associated with the radio link terminals and carrier terminations is recommended to be covered by a model generic for the complete node, e.g. [RFC8348] and it is thereby outside the scope of the radio link specific model.

### 6.3. Summary

The conclusions and recommendations from the analysis can be summarized as follows:

1. A Microwave Radio Link YANG Data Model should be defined with a scope enough to support the use cases and requirements in Sections 4 and 5 of this document.
2. Use the structure in the IETF: Radio Link Model [I-D.ietf-ccamp-mw-yang] as the starting point. It augments [RFC8343] and is thereby as required aligned with the structure of the models for management of the L2 and L3 domains.
3. Use established microwave equipment and radio standards, such as [EN302217-2], and the IETF: Radio Link Model [I-D.ietf-ccamp-mw-yang] and the ONF: Microwave Modeling [ONF-model] as the basis for the definition of the detailed leafs/parameters to support the specified use cases and requirements, and proposing new ones to cover identified gaps.
4. Add the required data nodes to describe the interface layering for the capacity provided by a radio link terminal and the associated Ethernet and TDM interfaces, using the principles and data nodes for interface layering described in [RFC8343] as a basis.
5. Include support for configuration of microwave specific alarms in the Microwave Radio Link model and rely on a generic model such as [I-D.ietf-ccamp-alarm-module] for notifications and alarm synchronization.
6. Use a generic model such as [RFC8348] for physical/equipment inventory.

### 7. Security Considerations

The configuration information may be considered sensitive or vulnerable in the network environments. Unauthorized access to configuration data nodes can have a negative effect on network operations, e.g., interrupting the ability to forward traffic, or increasing the interference level of the network. The status and inventory reveal some network information that could be very helpful to an attacker. A malicious attack to that information may result in a loss of customer data. Security issue concerning the access control to Management interfaces can be generally addressed by authentication techniques providing origin verification, integrity and confidentiality. In addition, management interfaces can be

physically or logically isolated, by configuring them to be only accessible out-of-band, through a system that is physically or logically separated from the rest of the network infrastructure. In case where management interfaces are accessible in-band at the client device or within the microwave transport network domain, filtering or firewalling techniques can be used to restrict unauthorized in-band traffic. Authentication techniques may be additionally used in all cases.

This framework describes the requirements and characteristics of a YANG Data Model for control and management of the radio link interfaces in a microwave node. It is supposed to be accessed via a management protocol with a secure transport layer, such as NETCONF [RFC6241].

## 8. IANA Considerations

This memo includes no request to IANA.

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A YANG Data Model for Microwave Radio Link  
draft-ietf-ccamp-mw-yang-01

Abstract

This document defines a YANG data model in order to control and manage the radio link interfaces, and the connectivity to packet (typically Ethernet) interfaces in a microwave/millimeter wave node.

Requirements Language

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

Status of This Memo

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## 1. Terminology and Definitions

The following terms are used in this document:

Carrier Termination (CT) is an interface for the capacity provided over the air by a single carrier. It is typically defined by its transmitting and receiving frequencies.

Radio Link Terminal (RLT) is an interface providing packet capacity and/or TDM capacity to the associated Ethernet and/or TDM interfaces in a node and used for setting up a transport service over a microwave/millimeter wave link.

The following acronyms are used in this document:

ACM Adaptive Coding Modulation

ATPC Automatic Transmit Power Control

CM Coding Modulation

CT Carrier Termination

RLT Radio Link Terminal

RTPC Remote Transmit Power Control

XPIC Cross Polarization Interference Cancellation

MIMO Multiple-Input Multiple-Output

## 2. Introduction

This document defines a YANG data model for management and control of the radio link interface(s) and the relationship to packet (typically Ethernet) and/or TDM interfaces in a microwave/millimeter wave node. ETSI EN 302 217 series defines the characteristics and requirements of microwave/millimeter wave equipment and antennas. Especially ETSI EN 302 217-2 [EN 302 217-2] specifies the essential parameters for the systems operating from 1.4GHz to 86GHz. The data model includes configuration and state data.

The design of the data model follows the framework for management and control of microwave and millimeter wave interface parameters defined in [I-D.ietf-ccamp-microwave-framework]. This framework identifies the need and the scope of the YANG data model, the use cases and requirements that the model needs to support. Moreover, it provides a detailed gap analysis to identify the missing parameters and functionalities of the existing and established models to support the specified use cases and requirements, and based on that recommends how the gaps should be filled with the development of the new model.

According to the conclusion of the gap analysis, the structure of the data model is based on the structure defined in [I-D.ahlberg-ccamp-microwave-radio-link] and it augments RFC 7223 to align with the same structure for management of the packet interfaces. More specifically, the model will include interface layering to manage the capacity provided by a radio link terminal for the associated Ethernet and TDM interfaces, using the principles for interface layering described in RFC 7223 as a basis.

The designed YANG data model uses established microwave equipment and radio standards, such as ETSI EN 302 217-2, and the IETF: Radio Link Model [I-D.ahlberg-ccamp-microwave-radio-link] and the ONF: Microwave Modeling [ONF-model] as the basis for the definition of the detailed leafs/parameters, and proposes new ones to cover identified gaps which are analysed in [I-D.ietf-ccamp-microwave-framework].

### 3. YANG Data Model (Tree Structure)

#### 3.1. the YANG Tree

```

module: ietf-microwave-radio-link
  +--rw radio-link-protection-groups
  |   +--rw radio-link-protection-group* [name]
  |   |   +--rw name string
  |   |   +--rw protection-architecture-type? identityref
  |   |   +--rw protection-operation-type? enumeration
  |   |   +--rw working-entity* if:interface-ref
  |   |   +--rw revertive-wait-to-restore? uint16
  |   |   +--rw radio-link-protection-members* if:interface-ref
  |   |   +---x protection-external-commands
  |   |   |   +---w input
  |   |   |   +---w protection-external-command? identityref
  |   +--ro radio-link-protection-groups-state
  |   |   +--ro radio-link-protection-group* [name]
  |   |   |   +--ro name string
  |   |   |   +--ro protection-status? identityref
  |   +--rw xpic-pairs {xpic}?
  |   |   +--rw xpic-pair* [name]
  |   |   |   +--rw name string
  |   |   |   +--rw enabled? boolean
  |   |   |   +--rw xpic-members* if:interface-ref
  |   +--rw mimo-groups {mimo}?
  |   |   +--rw mimo-group* [name]
  |   |   |   +--rw name string
  |   |   |   +--rw enabled? boolean
  |   |   |   +--rw mimo-members* if:interface-ref
  augment /if:interfaces/if:interface:
    +--rw id? string
    +--rw mode identityref
    +--rw carrier-terminations* if:interface-ref
    +--rw rlp-groups* leafref
    +--rw xpic-pairs*
    |   -> /xpic-pairs/xpic-pair/name {xpic}?
    +--rw mimo-group?
    |   -> /mimo-groups/mimo-group/name {mimo}?
    +--rw tdm-connections* [tdm-type] {tdm}?
    |   +--rw tdm-type identityref
    |   +--rw tdm-connections uint16
  augment /if:interfaces/if:interface:
    +--rw carrier-id? string
    +--rw tx-enabled? boolean
    +--rw tx-frequency uint32
    +--rw rx-frequency? uint32
    +--rw duplex-distance? uint32

```

```

    +--rw channel-separation          uint32
    +--rw polarization?               enumeration
    +--rw power-mode                  enumeration
    +--rw selected-output-power       power
    +--rw atpc-lower-threshold        power
    +--rw atpc-upper-threshold        power
    +--rw coding-modulation-mode      enumeration
    +--rw selected-cm                 identityref
    +--rw selected-min-acm            identityref
    +--rw selected-max-acm            identityref
    +--rw if-loop?                    enumeration
    +--rw rf-loop?                    enumeration
    +--rw ct-performance-thresholds
      +--rw received-level-alarm-threshold? power
      +--rw transmitted-level-alarm-threshold? power
      +--rw ber-alarm-threshold?       enumeration
augment /if:interfaces-state/if:interface:
    +--ro tx-oper-status?             enumeration
    +--ro actual-transmitted-level?   power
    +--ro actual-received-level?     power
    +--ro actual-tx-cm?               identityref
    +--ro actual-snr?                 decimal64
    +--ro actual-xpi?                 decimal64 {xpic}?
    +--ro capabilities
      +--ro min-tx-frequency?         uint32
      +--ro max-tx-frequency?         uint32
      +--ro min-rx-frequency?         uint32
      +--ro max-rx-frequency?         uint32
      +--ro available-min-output-power? power
      +--ro available-max-output-power? power
      +--ro available-min-acm?        identityref
      +--ro available-max-acm?        identityref
augment /if:interfaces-state/if:interface/if:statistics:
    +--ro bbe?                        yang:counter32
    +--ro es?                         yang:counter32
    +--ro ses?                        yang:counter32
    +--ro uas?                        yang:counter32
    +--ro min-rltm?                   power
    +--ro max-rltm?                   power
    +--ro min-tltm?                   power
    +--ro max-tltm?                   power

```

### 3.2. Explanation of the Microwave Data Model

The leaves in the Interface Management Module augmented by Radio Link Terminal (RLT) and Carrier Termination (CT) are not always relevant.



"/interfaces/interface/enabled" is not relevant for RLT. Enable and disable of an interface is done in the constituent CTs.

The packet related measurements "in-octets", "in-unicast-pkts", "in-broadcast-pkts", "in-multicast-pkts", "in-discards", "in-errors", "in-unknown-protos", "out-octets", "out-unicast-pkts", "out-broadcast-pkts", "out-multicast-pkts", "out-discards", "out-errors" are not within the scope of the microwave radio link domain and therefore not relevant for RLT and CT.

#### 4. YANG Module

```
<CODE BEGINS> file "ietf-microwave-radio-link.yang"

module ietf-microwave-radio-link {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-microwave-radio-link";
  prefix "mrl";

  import ietf-yang-types {
    prefix yang;
  }

  import ietf-interfaces {
    prefix if;
  }

  import iana-if-type {
    prefix ianaift;
  }

  organization
    "Internet Engineering Task Force (IETF) CCAMP WG";
  contact
    "
    WG List: <mailto:ccamp@ietf.org>

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    ";
```

```
description
  "This is a module for the entities in a generic microwave system.";

revision 2017-06-21 {
  description
    "Updated draft revision with updates of some descriptions to
    increase clarity and some minor adjustments of the model.";
  reference "";
}
revision 2016-12-22 {
  description
    "Draft revision covering a complete scope for configuration
    and state data for radio link interfaces.";
  reference "";
}
revision 2016-10-29 {
  description
    "Draft revision.";
  reference "";
}

/*
 * Features
 */

feature xpic {
  description
    "Indicates that the device supports XPIC.";
}

feature mimo {
  description
    "Indicates that the device supports MIMO.";
}

feature tdm {
  description
    "Indicates that the device supports TDM.";
}

/*
 * Interface identities
 */

identity radio-link-terminal {
  base ianaift:iana-interface-type;
  description
    "Interface identity for a radio link terminal.";
```

```
}

identity carrier-termination {
  base ianaift:iana-interface-type;
  description
    "Interface identity for a carrier termination.";
}

/*
 * Radio-link-terminal mode identities
 */

identity rlt-mode {
  description
    "A description of the mode in which the radio link
    terminal is configured. The format is X plus Y.
    X represent the number of bonded carrier terminations.
    Y represent the number of protecting carrier
    terminations.";
}

identity one-plus-zero {
  base rlt-mode;
  description
    "1 carrier termination only.";
}

identity one-plus-one {
  base rlt-mode;
  description
    "1 carrier termination
    and 1 protecting carrier termination.";
}

identity two-plus-zero {
  base rlt-mode;
  description
    "2 bonded carrier terminations.";
}

/*
 * Coding and modulation identities
 */

identity coding-modulation {
  description
    "The coding and modulation schemes.";
}
```

```
identity half-bpsk-strong {
  base coding-modulation;
  description
    "Half BPSK strong coding and modulation scheme.";
}

identity half-bpsk {
  base coding-modulation;
  description
    "Half BPSK coding and modulation scheme.";
}

identity half-bpsk-light {
  base coding-modulation;
  description
    "Half BPSK light coding and modulation scheme.";
}

identity bpsk-strong {
  base coding-modulation;
  description
    "BPSK strong coding and modulation scheme.";
}

identity bpsk {
  base coding-modulation;
  description
    "BPSK coding and modulation scheme.";
}

identity bpsk-light {
  base coding-modulation;
  description
    "BPSK light coding and modulation scheme.";
}

identity qpsk {
  base coding-modulation;
  description
    "QPSK coding and modulation scheme.";
}

identity qam-4-strong {
  base coding-modulation;
  description
    "4 QAM strong coding and modulation scheme.";
}
```

```
identity qam-4 {
  base coding-modulation;
  description
    "4 QAM coding and modulation scheme.";
}

identity qam-4-light {
  base coding-modulation;
  description
    "4 QAM light coding and modulation scheme.";
}

identity qam-16-strong {
  base coding-modulation;
  description
    "16 QAM strong coding and modulation scheme.";
}

identity qam-16 {
  base coding-modulation;
  description
    "16 QAM coding and modulation scheme.";
}

identity qam-16-light {
  base coding-modulation;
  description
    "16 QAM light coding and modulation scheme.";
}

identity qam-32-strong {
  base coding-modulation;
  description
    "32 QAM strong coding and modulation scheme.";
}

identity qam-32 {
  base coding-modulation;
  description
    "32 QAM coding and modulation scheme.";
}

identity qam-32-light {
  base coding-modulation;
  description
    "32 QAM light coding and modulation scheme.";
}
```

```
identity qam-64-strong {
  base coding-modulation;
  description
    "64 QAM strong coding and modulation scheme.";
}

identity qam-64 {
  base coding-modulation;
  description
    "64 QAM coding and modulation scheme.";
}

identity qam-64-light {
  base coding-modulation;
  description
    "64 QAM light coding and modulation scheme.";
}

identity qam-128-strong {
  base coding-modulation;
  description
    "128 QAM strong coding and modulation scheme.";
}

identity qam-128 {
  base coding-modulation;
  description
    "128 QAM coding and modulation scheme.";
}

identity qam-128-light {
  base coding-modulation;
  description
    "128 QAM light coding and modulation scheme.";
}

identity qam-256-strong {
  base coding-modulation;
  description
    "256 QAM strong coding and modulation scheme.";
}

identity qam-256 {
  base coding-modulation;
  description
    "256 QAM coding and modulation scheme.";
}
```

```
identity qam-256-light {
  base coding-modulation;
  description
    "256 QAM light coding and modulation scheme.";
}

identity qam-512-strong {
  base coding-modulation;
  description
    "512 QAM strong coding and modulation scheme.";
}

identity qam-512 {
  base coding-modulation;
  description
    "512 QAM coding and modulation scheme.";
}

identity qam-512-light {
  base coding-modulation;
  description
    "512 QAM light coding and modulation scheme.";
}

identity qam-1024-strong {
  base coding-modulation;
  description
    "1024 QAM strong coding and modulation scheme.";
}

identity qam-1024 {
  base coding-modulation;
  description
    "1024 QAM coding and modulation scheme.";
}

identity qam-1024-light {
  base coding-modulation;
  description
    "1024 QAM light coding and modulation scheme.";
}

identity qam-2048-strong {
  base coding-modulation;
  description
    "2048 QAM strong coding and modulation scheme.";
}
```

```
identity qam-2048 {
  base coding-modulation;
  description
    "2048 QAM coding and modulation scheme.";
}

identity qam-2048-light {
  base coding-modulation;
  description
    "2048 QAM light coding and modulation scheme.";
}

identity qam-4096-strong {
  base coding-modulation;
  description
    "4096 QAM strong coding and modulation scheme.";
}

identity qam-4096 {
  base coding-modulation;
  description
    "4096 QAM coding and modulation scheme.";
}

identity qam-4096-light {
  base coding-modulation;
  description
    "4096 QAM light coding and modulation scheme.";
}

/*
 * Protection architecture type identities
 */
identity protection-architecture-type {
  description
    "protection architecture type";
}

identity one-plus-one-type {
  base protection-architecture-type;
  description
    "One carrier termination and
     one protecting carrier termination.";
}

identity one-to-n-type {
  base protection-architecture-type;
  description
```



```
        "One carrier termination protecting
        n other carrier terminations.";
    }

    /*
    * Protection states identities
    */

    identity protection-states {
        description
            "Identities describing the status of the protection,
            in a group of carrier terminations configured in
            a radio link protection mode.";
    }

    identity unprotected {
        base protection-states;
        description "Not protected";
    }

    identity protected {
        base protection-states;
        description "Protected";
    }

    identity unable-to-protect {
        base protection-states;
        description "Unable to protect";
    }

    /*
    * protection-external-commands identities
    */

    identity protection-external-commands{
        description
            "Protection external commands for trouble shooting purpose.";
    }

    identity manual-switch{
        base protection-external-commands;
        description
            "A switch action initiated by an operator command. It switches
            normal traffic signal to the protection transport entity.";
    }

    identity forced-switch{
        base protection-external-commands;
```

```
    description
      "A switch action initiated by an operator command. It switches
      normal traffic signal to the protection transport entity and
      forces it to remain on that entity even when criteria for
      switching back to the original entity are fulfilled.";
  }

/*
 * TDM-type identities
 */

identity tdm-type {
  description
    "A description of the type of TDM connection,
    also indicating the supported capacity of the
    connection.";
}

identity E1 {
  base tdm-type;
  description
    "E1 connection, 2,048 Mbit/s.";
}

identity STM-1 {
  base tdm-type;
  description
    "STM-1 connection, 155,52 Mbit/s.";
}

/*
 * Typedefs
 */

typedef power {
  type decimal64 {
    fraction-digits 1;
  }
  description
    "Type used for power values, selected and measured.";
}

/*
 * Radio Link Terminal (RLT) - Configuration data nodes
 */

augment "/if:interfaces/if:interface" {
  when "if:type = 'mrl:radio-link-terminal'";
```

```
description
  "Addition of data nodes for radio link terminal to
  the standard Interface data model, for interfaces of
  the type 'radio-link-terminal'.";

leaf id {
  type string;
  default "";
  description
    "ID of the radio link terminal. Used by far-end when
    checking that it's connected to the correct RLT.";
}

leaf mode {
  type identityref {
    base rlt-mode;
  }
  mandatory true;
  description
    "A description of the mode in which the radio link
    terminal is configured. The format is X plus Y.
    X represent the number of bonded carrier terminations.
    Y represent the number of protecting carrier
    terminations.";
}

leaf-list carrier-terminations {
  type if:interface-ref;
  must "/if:interfaces/if:interface[if:name = current()]"
    + "/if:type = 'mrl:carrier-termination'" {
    description
      "The type of interface must be
      'carrier-termination'.";
  }
  min-elements 1;
  description
    "A list of references to carrier terminations
    included in the radio link terminal.";
}

leaf-list rlp-groups {
  type leafref {
    path "/mrl:radio-link-protection-groups/"
      + "mrl:radio-link-protection-group/mrl:name";
  }
  description
    "A list of references to the carrier termination
    groups configured for radio link protection in this
```

```
        radio link terminal.";
    }

    leaf-list xpics {
        if-feature xpics;
        type leafref {
            path "/mrl:xpics/mrl:xpic-pair/mrl:name";
        }
        description
            "A list of references to the XPIC pairs used in this
            radio link terminal. One pair can be used by two
            terminals.";
    }

    leaf mimo-group {
        if-feature mimo;
        type leafref {
            path "/mrl:mimo-groups/mrl:mimo-group/mrl:name";
        }
        description
            "A reference to the MIMO group used in this
            radio link terminal. One group can be used by more
            than one terminal.";
    }

    list tdm-connections {
        if-feature tdm;
        key "tdm-type";
        description
            "A list stating the number of active TDM connections of
            a specified tdm-type that is configured to be supported
            by the RLT.";
        leaf tdm-type {
            type identityref {
                base tdm-type;
            }
            description
                "The type of TDM connection, which also indicates
                the supported capacity.";
        }
        leaf tdm-connections {
            type uint16;
            mandatory true;
            description "Number of connections of the specified type.";
        }
    }
}
```

```
/*
 * Carrier Termination - Configuration data nodes
 */

augment "/if:interfaces/if:interface" {
  when "if:type = 'mrl:carrier-termination'";
  description
    "Addition of data nodes for carrier termination to the
    standard Interface data model, for interfaces of the type
    'carrier-termination'.";

  leaf carrier-id {
    type string;
    default "A";
    description
      "ID of the carrier. (e.g. A, B, C or D)
      Used in XPIC & MIMO configurations to check that the
      carrier termination is connected to the correct far-end
      carrier termination. Should be the same carrier ID on
      both sides of the hop.
      Defaulted when not MIMO or XPIC.";
  }

  leaf tx-enabled {
    type boolean;
    default "false";
    description
      "Disables (false) or enables (true) the transmitter.
      Only applicable when the interface is enabled
      (interface:enabled = true) otherwise it's always
      disabled.";
  }

  leaf tx-frequency {
    type uint32;
    units "kHz";
    mandatory true;
    description
      "Selected transmitter frequency.";
  }

  leaf rx-frequency {
    type uint32;
    units "kHz";
    description
      "Selected receiver frequency.
      Overrides existing value in duplex-distance.
      Calculated from tx-frequency and duplex-distance if
```

```
        only duplex-distance is configured.
        Must match duplex-distance if both leaves are
        configured in a single operation.";
    }

    leaf duplex-distance {
        type uint32;
        units "kHz";
        description
            "Distance between Tx & Rx frequencies.
            Used to calculate rx-frequency when
            rx-frequency is not specifically configured.
            Overrides existing value in rx-frequency.
            Calculated from tx-frequency and rx-frequency if only
            rx-frequency is configured.
            Must match rx-frequency if both leaves are configured
            in a single operation.";
    }

    leaf channel-separation {
        type uint32;
        units "kHz";
        mandatory true;
        description
            "The amount of bandwidth allocated to a carrier.";
    }

    leaf polarization {
        type enumeration {
            enum "horizontal" {
                description "Horizontal polarization.";
            }
            enum "vertical" {
                description "Vertical polarization.";
            }
            enum "not-specified" {
                description "Polarization not specified.";
            }
        }
        default "not-specified";
        description
            "Polarization - A textual description for info only.";
    }

    leaf power-mode {
        type enumeration {
            enum rtpc {
                description "Remote Transmit Power Control (RTPC).";
            }
        }
    }
```

```
    }
    enum atpc {
        description "Automatic Transmit Power Control (ATPC).";
    }
}
mandatory true;
description
    "A choice of Remote Transmit Power Control (RTPC)
    or Automatic Transmit Power Control (ATPC).";
}

leaf selected-output-power {
    type power {
        range "-99..40";
    }
    units "dBm";
    mandatory true;
    description
        "Selected output power in RTPC mode and selected maximum
        output power in ATPC mode. Minimum output power in ATPC mode
        is the same as the system capability,
        available-min-output-power.";
}

leaf atpc-lower-threshold {
    when "../power-mode = 'atpc'";
    type power {
        range "-99..-30";
    }
    units "dBm";
    mandatory true;
    description
        "The lower threshold for the input power at far-end used in
        the ATPC mode.";
}

leaf atpc-upper-threshold {
    when "../power-mode = 'atpc'";
    type power {
        range "-99..-30";
    }
    units "dBm";
    mandatory true;
    description
        "The upper threshold for the input power at far-end used in
        the ATPC mode.";
}
```

```
leaf coding-modulation-mode {
  type enumeration {
    enum fixed {
      description "Fixed coding/modulation.";
    }
    enum adaptive {
      description "Adaptive coding/modulation.";
    }
  }
  mandatory true;
  description
    "A selection of fixed or
     adaptive coding/modulation mode.";
}

leaf selected-cm {
  when "../coding-modulation-mode = 'fixed'";
  type identityref {
    base coding-modulation;
  }
  mandatory true;
  description
    "Selected fixed coding/modulation.";
}

leaf selected-min-acm {
  when "../coding-modulation-mode = 'adaptive'";
  type identityref {
    base coding-modulation;
  }
  mandatory true;
  description
    "Selected minimum coding/modulation.
     Adaptive coding/modulation shall not go
     below this value.";
}

leaf selected-max-acm {
  when "../coding-modulation-mode = 'adaptive'";
  type identityref {
    base coding-modulation;
  }
  mandatory true;
  description
    "Selected maximum coding/modulation.
     Adaptive coding/modulation shall not go
     above this value.";
}
```



```
leaf if-loop {
  type enumeration {
    enum disabled {
      description "Disables the IF Loop.";
    }
    enum client {
      description "Loops the signal back to the client side.";
    }
    enum radio {
      description "Loops the signal back to the radio side.";
    }
  }
  default "disabled";
  description
    "Enable (client/radio) or disable (disabled) the IF loop,
    which loops the signal back to the client side or
    the radio side.";
}

leaf rf-loop {
  type enumeration {
    enum disabled {
      description "Disables the RF Loop.";
    }
    enum client {
      description "Loops the signal back to the client side.";
    }
    enum radio {
      description "Loops the signal back to the radio side.";
    }
  }
  default "disabled";
  description
    "Enable (client/radio) or disable (disabled) the RF loop,
    which loops the signal back to the client side or
    the radio side.";
}

container ct-performance-thresholds {
  description
    "Specification of thresholds for when alarms should
    be sent and cleared for various performance counters.";

  leaf received-level-alarm-threshold {
    type power {
      range "-99..-30";
    }
    units "dBm";
  }
}
```

```
    default "-99";
    description
        "An alarm is sent when the received power level is
        below the specified threshold.";
}

leaf transmitted-level-alarm-threshold {
    type power {
        range "-99..40";
    }
    units "dBm";
    default "-99";
    description
        "An alarm is sent when the transmitted power level is
        below the specified threshold.";
}

leaf ber-alarm-threshold {
    type enumeration {
        enum "10e-9" {
            description "Threshold at 10e-9.";
        }
        enum "10e-8" {
            description "Threshold at 10e-8.";
        }
        enum "10e-7" {
            description "Threshold at 10e-7.";
        }
        enum "10e-6" {
            description "Threshold at 10e-6.";
        }
        enum "10e-5" {
            description "Threshold at 10e-5.";
        }
        enum "10e-4" {
            description "Threshold at 10e-4.";
        }
        enum "10e-3" {
            description "Threshold at 10e-3.";
        }
        enum "10e-2" {
            description "Threshold at 10e-2.";
        }
        enum "10e-1" {
            description "Threshold at 10e-1.";
        }
    }
    default "10e-6";
}
```

```
        description
            "Specification of at which BER an alarm should
             be raised.";
    }
}

/*
 * Radio Link Terminal - Operational state data nodes
 * Currently nothing in addition to the general
 * interface-state model.
 */

/*
 * Carrier Termination - Operational state data nodes
 */

augment "/if:interfaces-state/if:interface" {
    when "if:type = 'mrl:carrier-termination'";
    description
        "Addition of state data nodes for carrier termination to
         the standard Interface state data model, for interfaces of
         the type 'carrier-termination'.";

    leaf tx-oper-status {
        type enumeration {
            enum "off" {
                description "Transmitter is off.";
            }
            enum "on" {
                description "Transmitter is on.";
            }
            enum "standby" {
                description "Transmitter is in standby.";
            }
        }
        description
            "Shows the operative status of the transmitter.";
    }

    leaf actual-transmitted-level {
        type power {
            range "-99..40";
        }
        units "dBm";
        description
            "Actual transmitted power level (0.1 dBm resolution).";
    }
}
```

```
leaf actual-received-level {
  type power {
    range "-99..-20";
  }
  units "dBm";
  description
    "Actual received power level (0.1 dBm resolution).";
}

leaf actual-tx-cm {
  type identityref {
    base coding-modulation;
  }
  description
    "Actual coding/modulation in transmitting direction.";
}

leaf actual-snr {
  type decimal64 {
    fraction-digits 1;
    range "0..99";
  }
  units "dB";
  description
    "Actual signal to noise plus interference ratio.
    (0.1 dB resolution).";
}

leaf actual-xpi {
  if-feature xpica;
  type decimal64 {
    fraction-digits 1;
    range "0..99";
  }
  units "dB";
  description
    "The actual carrier to cross-polar interference.
    Only valid if XPIC is enabled. (0.1 dB resolution).";
}

container capabilities {
  description
    "Capabilities of the the installed equipment and
    some selected configurations.";

  leaf min-tx-frequency {
    type uint32;
    units "kHz";
  }
}
```

```
        description
            "Minimum Tx frequency possible to use.";
    }

    leaf max-tx-frequency {
        type uint32;
        units "kHz";
        description
            "Maximum Tx frequency possible to use.";
    }

    leaf min-rx-frequency {
        type uint32;
        units "kHz";
        description
            "Minimum Rx frequency possible to use.";
    }

    leaf max-rx-frequency {
        type uint32;
        units "kHz";
        description
            "Maximum Tx frequency possible to use.";
    }

    leaf available-min-output-power {
        type power;
        units "dBm";
        description
            "The minimum output power supported.";
    }

    leaf available-max-output-power {
        type power;
        units "dBm";
        description
            "The maximum output power supported.";
    }

    leaf available-min-acm {
        type identityref {
            base coding-modulation;
        }
        description
            "Minimum coding-modulation possible to use.";
    }

    leaf available-max-acm {
```

```
        type identityref {
            base coding-modulation;
        }
        description
            "Maximum coding-modulation possible to use.";
    }
}

augment "/if:interfaces-state/if:interface/if:statistics" {
    when "../if:type = 'mrl:carrier-termination'";
    description
        "Addition of state data nodes in the container statistics
        for carrier terminations to the standard Interface data
        model, for interfaces of the type 'carrier-termination'.";

    leaf bbe {
        type yang:counter32;
        units "number of block errors";
        description
            "Number of Background Block Errors (BBE) during the
            interval. A BBE is an errored block not occurring as
            part of an SES.";
    }

    leaf es {
        type yang:counter32;
        units "seconds";
        description
            "Number of Errored Seconds (ES) since last reset.
            An ES is a one-second period with one or more errored
            blocks or at least one defect.";
    }

    leaf ses {
        type yang:counter32;
        units "seconds";
        description
            "Number of Severely Errored Seconds (SES) during the
            interval. SES is a one-second period which contains
            equal or more than 30% errored blocks or at least
            one defect. SES is a subset of ES.";
    }

    leaf uas {
        type yang:counter32;
        units "seconds";
        description
```

```
        "Number of Unavailable Seconds (UAS), that is, the
        total time that the node has been unavailable during
        a fixed measurement interval.";
    }

    leaf min-rltm {
        type power {
            range "-99..-20";
        }
        units "dBm";
        description
            "Minimum received power level since last reset.";
    }

    leaf max-rltm {
        type power {
            range "-99..-20";
        }
        units "dBm";
        description
            "Maximum received power level since last reset.";
    }

    leaf min-tltm {
        type power {
            range "-99..40";
        }
        units "dBm";
        description
            "Minimum transmitted power level since last reset.";
    }

    leaf max-tltm {
        type power {
            range "-99..40";
        }
        units "dBm";
        description
            "Maximum transmitted power level since last reset.";
    }
}

/*
 * Radio Link Protection Groups - Configuration data nodes
 */

container radio-link-protection-groups {
    description
```

"Configuration of radio link protected groups (1+1) of carrier terminations in a radio link. More than one protected group per radio-link-terminal is allowed.";

```
list radio-link-protection-group {
  key "name";
  description
    "List of protected groups of carrier terminations
    in a radio link.";

  leaf name {
    type string;
    description
      "Name used for identification of the radio
      link protection group";
  }

  leaf protection-architecture-type {
    type identityref{
      base protection-architecture-type;
    }
    default "one-plus-one-type";
    description
      "The type of protection architecture used,
      e.g. one carrier termination protecting one or
      several other carrier terminations.";
  }

  leaf protection-operation-type {
    type enumeration {
      enum "non-revertive" {
        description
          "In non revertive operation, the traffic
          does not return to the working carrier termination
          if the switch requests are terminated. ";
      }
      enum "revertive" {
        description
          "In revertive operation, the traffic always
          returns to (or remains on) the working
          carrier termination if the switch requests are
          terminated. ";
      }
    }
    default "non-revertive";
    description
      "The type of protection operation, i.e. revertive
      or non-revertive operation.";
```



```
}

leaf-list working-entity {
  when "../protection-operation-type = 'revertive'";
  type if:interface-ref;
  must "/if:interfaces/if:interface[if:name = current()]"
    + "/if:type = 'mrl:carrier-termination'" {
    description
      "The type of a working-entity must be
       'carrier-termination'.";
  }
  min-elements 1;
  description
    "The carrier terminations over which the traffic
     normally should be transported over when there
     is no need to use the protecting carrier termination.";
}

leaf revertive-wait-to-restore {
  when "../protection-operation-type = 'revertive'";
  type uint16;
  units "seconds";
  default "0";
  description
    "The time to wait before switching back to the
     working carrier termination if protection-operation-type
     is revertive.";
}

leaf-list radio-link-protection-members {
  type if:interface-ref;
  must "/if:interfaces/if:interface[if:name = current()]"
    + "/if:type = 'mrl:carrier-termination'" {
    description
      "The type of a protection member must be
       'carrier-termination'.";
  }
  min-elements 2;
  description
    "Association to a group of carrier terminations
     configured for radio link protection and used in
     the radio link terminal.";
}

action protection-external-commands {
  input {
    leaf protection-external-command {
      type identityref {
```

```
        base protection-external-commands;
      }
      description
        "Execution of protection external commands for
        trouble shooting purpose.";
    }
  }
}

/*
 * Radio Link Protection Groups - Operational state data nodes
 */

container radio-link-protection-groups-state {
  config false;
  description
    "State data for radio link protected groups of
    carrier terminations in a radio link.";

  list radio-link-protection-group {
    key "name";
    description
      "List of protected groups of carrier terminations
      in a radio link.";

    leaf name {
      type string;
      description
        "Name used for identification of the radio
        link protection group.";
    }

    leaf protection-status {
      type identityref {
        base protection-states;
      }
      description
        "Status of the protection, in a group of carrier
        terminations configured in a radio link protection
        mode.";
    }
  }
}

/*
 * XPIC & MIMO groups - Configuration data nodes
```

```
*/

container xpic-pairs {
  if-feature xpic;
  description
    "Configuration of carrier termination pairs
    for operation in XPIC mode.";

  list xpic-pair {
    key "name";
    description
      "List of carrier termination pairs in XPIC mode.";

    leaf name {
      type string;
      description
        "Name used for identification of the XPIC pair.";
    }

    leaf enabled {
      type boolean;
      default "false";
      description
        "Enable(true)/disable(false) XPIC";
    }

    leaf-list xpic-members {
      type if:interface-ref;
      must "/if:interfaces/if:interface[if:name = current()]"
        + "/if:type = 'mrl:carrier-termination'" {
        description
          "The type of a xpic-member must be
          'carrier-termination'.";
      }
      min-elements 2;
      max-elements 2;
      description
        "Association to XPIC pairs used in the radio link
        terminal.";
    }
  }
}

container mimo-groups {
  if-feature mimo;
  description
    "Configuration of carrier terminations
    for operation in MIMO mode.";
```

```
list mimo-group {
  key "name";
  description
    "List of carrier terminations in MIMO mode.";

  leaf name {
    type string;
    description
      "Name used for identification of the MIMO group.";
  }

  leaf enabled {
    type boolean;
    default "false";
    description
      "Enable(true)/disable(false) MIMO";
  }

  leaf-list mimo-members {
    type if:interface-ref;
    must "/if:interfaces/if:interface[if:name = current()]"
      + "/if:type = 'mrl:carrier-termination'" {
      description
        "The type of a mimo-member must be
         'carrier-termination'.";
    }
    min-elements 2;
    description
      "Association to a MIMO group if used in the radio
       link terminal.";
  }
}

}

}

<CODE ENDS>
```

## 5. Security Considerations

The YANG module defined in this memo is designed to be accessed via the NETCONF protocol [RFC6241]. The lowest NETCONF layer is the secure transport layer and the mandatory-to-implement secure transport is SSH [RFC6242]. The NETCONF access control model [RFC6536] provides the means to restrict access for particular NETCONF users to a pre-configured subset of all available NETCONF protocol operations and content.

There are a number of data nodes defined in the YANG module which are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., <editconfig>) to these data nodes without proper protection can have a negative effect on network operations.

The security considerations of [RFC7223] also apply to this document.

## 6. IANA Considerations

TBD.

## 7. References

### 7.1. Normative References

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A YANG Data Model for Microwave Radio Link  
draft-ietf-ccamp-mw-yang-13

Abstract

This document defines a YANG data model for control and management of the radio link interfaces, and their connectivity to packet (typically Ethernet) interfaces in a microwave/millimeter wave node. The data nodes for management of the interface protection functionality is broken out into a separate and generic YANG data model in order to make it available also for other interface types.

RFC Ed. Note

// RFC Ed.: replace all XXXX throughout the document with actual RFC numbers and remove this note

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## 1. Introduction

This document defines a YANG data model for management and control of the radio link interface(s) and the relationship to packet (typically Ethernet) and/or TDM interfaces in a microwave/millimeter wave node. ETSI EN 302 217 series defines the characteristics and requirements of microwave/millimeter wave equipment and antennas. Especially ETSI EN 302 217-2 [EN302217-2] specifies the essential parameters for the systems operating from 1.4GHz to 86GHz. The data model includes

configuration and state data according to the new Network Management Datastore Architecture [RFC8342].

The design of the data model follows the framework for management and control of microwave and millimeter wave interface parameters defined in [RFC8432]. This framework identifies the need and the scope of the YANG data model, the use cases and requirements that the model needs to support. Moreover, it provides a detailed gap analysis to identify the missing parameters and functionalities of the existing and established models to support the specified use cases and requirements, and based on that recommends how the gaps should be filled with the development of the new model. According to the conclusion of the gap analysis, the structure of the data model is based on the structure defined in [I-D.ahlberg-ccamp-microwave-radio-link] and it augments [RFC8343] to align with the same structure for management of the packet interfaces. More specifically, the model will include interface layering to manage the capacity provided by a radio link terminal for the associated Ethernet and TDM interfaces, using the principles for interface layering described in [RFC8343] as a basis.

The data nodes for management of the interface protection functionality is broken out into a separate and generic YANG data module in order to make it available also for other interface types.

The designed YANG data model uses established microwave equipment and radio standards, such as ETSI EN 302 217-2, and the IETF: Radio Link Model [I-D.ahlberg-ccamp-microwave-radio-link] and the ONF: Microwave Modeling [ONF-model] as the basis for the definition of the detailed leafs/parameters, and proposes new ones to cover identified gaps which are analyzed in [RFC8432].

### 1.1. Terminology and Definitions

The following terms are used in this document:

Carrier Termination (CT) is an interface for the capacity provided over the air by a single carrier. It is typically defined by its transmitting and receiving frequencies.

Radio Link Terminal (RLT) is an interface providing packet capacity and/or TDM capacity to the associated Ethernet and/or TDM interfaces in a node and used for setting up a transport service over a microwave/millimeter wave link.

The following acronyms are used in this document:

ACM Adaptive Coding Modulation

ATPC Automatic Transmit Power Control

BBE Background Block Errors

BER Bit Error Ratio

BPSK Binary Phase-Shift Keying

CM Coding Modulation

CT Carrier Termination

ES Errored Seconds

IF Intermediate Frequency

MIMO Multiple-Input Multiple-Output

RF Radio Frequency

RLT Radio Link Terminal

QAM Quadrature Amplitude Modulation

QPSK Quadrature Phase-Shift Keying

RTPC Remote Transmit Power Control

SES Severely Errored Seconds

TDM Time-Division Multiplexing

UAS Unavailable Seconds

XPIC Cross Polarization Interference Cancellation

## 1.2. Tree Structure

A simplified graphical representation of the data model is used in chapter 3.1 of this document. The meaning of the symbols in these diagrams is defined in [RFC8340].

## 2. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP

14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

### 3. Microwave Radio Link YANG Data Model

#### 3.1. YANG Tree

```

module: ietf-microwave-radio-link
  +--rw radio-link-protection-groups
  |   +--rw protection-group* [name]
  |   |   +--rw name string
  |   |   +--rw protection-architecture-type? identityref
  |   |   +--rw members* if:interface-ref
  |   |   +--rw operation-type? enumeration
  |   |   +--rw working-entity* if:interface-ref
  |   |   +--rw revertive-wait-to-restore? uint16
  |   |   +--rw hold-off-timer? uint16
  |   |   +--ro status? identityref
  |   |   +---x manual-switch-working
  |   |   +---x manual-switch-protection
  |   |   +---x forced-switch
  |   |   +---x lockout-of-protection
  |   |   +---x freeze
  |   |   +---x exercise
  |   |   +---x clear
  |   +--rw xp-pic-pairs {xp-pic}?
  |   |   +--rw xp-pic-pair* [name]
  |   |   |   +--rw name string
  |   |   |   +--rw enabled? boolean
  |   |   |   +--rw members* if:interface-ref
  |   +--rw mimo-groups {mimo}?
  |   |   +--rw mimo-group* [name]
  |   |   |   +--rw name string
  |   |   |   +--rw enabled? boolean
  |   |   |   +--rw members* if:interface-ref
  augment /if:interfaces/if:interface:
    +--rw id? string
    +--rw mode identityref
    +--rw carrier-terminations* if:interface-ref
    +--rw rlp-groups*
    |   -> /radio-link-protection-groups/protection-group/name
    +--rw xp-pic-pairs* -> /xp-pic-pairs/xp-pic-pair/name
    |   {xp-pic}?
    +--rw mimo-groups* -> /mimo-groups/mimo-group/name
    |   {mimo}?
    +--rw tdm-connections* [tdm-type] {tdm}?
    |   +--rw tdm-type identityref

```

```

    +--rw tdm-connections          uint16
augment /if:interfaces/if:interface:
+--rw carrier-id?                  string
+--rw tx-enabled?                  boolean
+--ro tx-oper-status?              enumeration
+--rw tx-frequency                 uint32
+--rw (freq-or-distance)
|   +--:(rx-frequency)
|   |   +--rw rx-frequency?        uint32
|   +--:(duplex-distance)
|   |   +--rw duplex-distance?     int32
+--ro actual-rx-frequency?         uint32
+--ro actual-duplex-distance?     uint32
+--rw channel-separation          uint32
+--rw polarization?              enumeration
+--rw (power-mode)
|   +--:(rtpc)
|   |   +--rw rtpc
|   |   |   +--rw maximum-nominal-power    power
|   +--:(atpc)
|   |   +--rw atpc
|   |   |   +--rw maximum-nominal-power    power
|   |   |   +--rw atpc-lower-threshold     power
|   |   |   +--rw atpc-upper-threshold     power
+--ro actual-transmitted-level?    power
+--ro actual-received-level?       power
+--rw (coding-modulation-mode)
|   +--:(single)
|   |   +--rw single
|   |   |   +--rw selected-cm            identityref
|   +--:(adaptive)
|   |   +--rw adaptive
|   |   |   +--rw selected-min-acm        identityref
|   |   |   +--rw selected-max-acm        identityref
+--ro actual-tx-cm?               identityref
+--ro actual-snr?                 decimal64
+--ro actual-xpi?                 decimal64 {xplic}?
+--rw ct-performance-thresholds
|   +--rw received-level-alarm-threshold?    power
|   +--rw transmitted-level-alarm-threshold? power
|   +--rw ber-alarm-threshold?               enumeration
+--rw if-loop?                     enumeration
+--rw rf-loop?                     enumeration
+--ro capabilities
|   +--ro min-tx-frequency?          uint32
|   +--ro max-tx-frequency?          uint32
|   +--ro min-rx-frequency?          uint32
|   +--ro max-rx-frequency?          uint32

```

```

    |   +--ro minimum-power?           power
    |   +--ro maximum-available-power? power
    |   +--ro available-min-acm?       identityref
    |   +--ro available-max-acm?       identityref
    +--ro error-performance-statistics
    |   +--ro bbe?      yang:counter32
    |   +--ro es?       yang:counter32
    |   +--ro ses?      yang:counter32
    |   +--ro uas?      yang:counter32
    +--ro radio-performance-statistics
    |   +--ro min-rltm?  power
    |   +--ro max-rltm?  power
    |   +--ro min-tltm?  power
    |   +--ro max-tltm?  power

```

### 3.2. Explanation of the Microwave Data Model

The leafs in the Interface Management Module augmented by Radio Link Terminal (RLT) and Carrier Termination (CT) are not always applicable.

"/interfaces/interface/enabled" is not applicable for RLT. Enable and disable of an interface is done in the constituent CTs.

The packet related measurements "in-octets", "in-unicast-pkts", "in-broadcast-pkts", "in-multicast-pkts", "in-discards", "in-errors", "in-unknown-protos", "out-octets", "out-unicast-pkts", "out-broadcast-pkts", "out-multicast-pkts", "out-discards", "out-errors" are not within the scope of the microwave radio link domain and therefore not applicable for RLT and CT.

### 4. Microwave Radio Link YANG Module

This module imports typedefs and modules from [RFC6991], [RFC8343] and [RFC7224], and it references [TR102311], [EN302217-1], [EN301129], and [G.826].

```

<CODE BEGINS> file "ietf-microwave-radio-link@2018-11-28.yang"

module ietf-microwave-radio-link {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-microwave-radio-link";
  prefix mrl;

  import ietf-yang-types {
    prefix yang;

```

```
    reference "RFC 6991";
}

import iana-if-type {
    prefix ianaift;
}

import ietf-interfaces {
    prefix if;
    reference "RFC 8343";
}

import ietf-interface-protection {
    prefix ifprot;
    reference "RFC XXXX";
}

import ietf-microwave-types {
    prefix mw-types;
    reference "RFC XXXX";
}

organization
    "Internet Engineering Task Force (IETF) CCAMP WG";

contact
    "WG List: <mailto:ccamp@ietf.org>"

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description
    "This is a module for the entities in
    a generic microwave system.

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```
revision 2018-11-28 {
  description "Initial revision.";
  reference "RFC XXXX: A YANG Data Model for Microwave Radio Link";
}

/*
 * Features
 */

feature xpic {
  description
    "Indicates that the device supports XPIC.";
  reference "ETSI TR 102 311";
}

feature mimo {
  description
    "Indicates that the device supports MIMO.";
  reference "ETSI TR 102 311";
}

feature tdm {
  description
    "Indicates that the device supports TDM.";
}

/*
 * Typedefs
 */

typedef power {
  type decimal64 {
    fraction-digits 1;
  }
  description
    "Type used for power values, selected and measured.";
}

/*
 * Radio Link Terminal (RLT)
 */
```



```
*/

augment "/if:interfaces/if:interface" {
  when "derived-from-or-self(if:type, "
    + "'ianaift:radio-link-terminal')";
  description
    "Addition of data nodes for radio link terminal to
    the standard Interface data model, for interfaces of
    the type 'radio-link-terminal'.";

  leaf id {
    type string;
    description
      "Descriptive identity of the radio link terminal used by
      far-end RLT to check that it's connected to the correct
      near-end RLT. Does not need to be configured if this check
      is not used.";
  }

  leaf mode {
    type identityref {
      base mw-types:rlt-mode;
    }
    mandatory true;
    description
      "A description of the mode in which the radio link
      terminal is configured. The format is X plus Y.
      X represent the number of bonded carrier terminations.
      Y represent the number of protecting carrier
      terminations.";
  }

  leaf-list carrier-terminations {
    type if:interface-ref;
    must "derived-from-or-self(/if:interfaces/if:interface"
      + "[if:name = current()]"
      + "/if:type, 'ianaift:carrier-termination')" {
      description
        "The type of interface must be
        'carrier-termination'.";
    }
    min-elements 1;
    description
      "A list of references to carrier terminations
      included in the radio link terminal.";
  }

  leaf-list rlp-groups {
```

```
    type leafref {
      path "/mrl:radio-link-protection-groups/"
        + "mrl:protection-group/mrl:name";
    }
    description
      "A list of references to the carrier termination
      groups configured for radio link protection in this
      radio link terminal.";
  }

  leaf-list xpics {
    if-feature xpics;
    type leafref {
      path "/mrl:xpics/mrl:xpic-pair/mrl:name";
    }

    description
      "A list of references to the XPIC pairs used in this
      radio link terminal. One pair can be used by two
      terminals.";
    reference "ETSI TR 102 311";
  }

  leaf-list mimo-groups {
    if-feature mimo;
    type leafref {
      path "/mrl:mimo-groups/mrl:mimo-group/mrl:name";
    }
    description
      "A reference to the MIMO group used in this
      radio link terminal. One group can be used by more
      than one terminal.";
    reference "ETSI TR 102 311";
  }

  list tdm-connections {
    if-feature tdm;
    key "tdm-type";
    description
      "A list stating the number of active TDM connections
      of a specified tdm-type that is configured to be
      supported by the RLT.";
    leaf tdm-type {
      type identityref {
        base mw-types:tdm-type;
      }
      description
        "The type of TDM connection, which also indicates
```

```
        the supported capacity.";
    }
    leaf tdm-connections {
        type uint16;
        mandatory true;
        description
            "Number of connections of the specified type.";
    }
}

/*
 * Carrier Termination
 */

augment "/if:interfaces/if:interface" {
    when "derived-from-or-self(if:type, "
        + "'ianaift:carrier-termination')";

    description
        "Addition of data nodes for carrier termination to
        the standard Interface data model, for interfaces
        of the type 'carrier-termination'.";

    leaf carrier-id {
        type string;
        default "A";
        description
            "ID of the carrier. (e.g. A, B, C or D)
            Used in XPIC & MIMO configurations to check that
            the carrier termination is connected to the correct
            far-end carrier termination. Should be the same
            carrier ID on both sides of the hop.
            Left as default value when MIMO and XPIC are not in use.";
    }

    leaf tx-enabled {
        type boolean;
        default "false";
        description
            "Disables (false) or enables (true) the transmitter.
            Only applicable when the interface is enabled
            (interface:enabled = true) otherwise it's always
            disabled.";
    }

    leaf tx-oper-status {
        type enumeration {

```

```
    enum "off" {
        description "Transmitter is off.";
    }
    enum "on" {
        description "Transmitter is on.";
    }
    enum "standby" {
        description "Transmitter is in standby.";
    }
}
config false;
description
    "Shows the operative status of the transmitter.";
}

leaf tx-frequency {
    type uint32;
    units "kHz";
    mandatory true;
    description
        "Selected transmitter frequency.";
}

choice freq-or-distance {
    leaf rx-frequency {
        type uint32;
        units "kHz";
        description
            "Selected receiver frequency.";
    }
    leaf duplex-distance {
        type int32;
        units "kHz";
        description
            "Distance between transmitter and receiver frequencies.";
    }
}
mandatory true;
description
    "A choice to configure rx-frequency directly or by computing
    it as duplex-distance subtracted from tx-frequency." ;
}

leaf actual-rx-frequency {
    type uint32;
    units "kHz";
    config false;
    description
        "Computed receiver frequency.";
```

```
}

leaf actual-duplex-distance {
  type uint32;
  units "kHz";
  config false;
  description
    "Computed distance between Tx & Rx frequencies.";
}

leaf channel-separation {
  type uint32;
  units "kHz";
  mandatory true;
  description
    "The amount of bandwidth allocated to a carrier. The distance
    between adjacent channels in a radio frequency channels
    arrangement";
  reference "ETSI EN 302 217-1";
}

leaf polarization {
  type enumeration {
    enum "horizontal" {
      description "Horizontal polarization.";
    }
    enum "vertical" {
      description "Vertical polarization.";
    }
    enum "not-specified" {
      description "Polarization not specified.";
    }
  }

  default "not-specified";
  description
    "Polarization - A textual description for info only.";
}

choice power-mode {
  container rtpc {
    description
      "Remote Transmit Power Control (RTPC).";
    reference "ETSI EN 302 217-1";
    leaf maximum-nominal-power {
      type power {
        range "-99..99";
      }
    }
  }
}
```

```
        units "dBm";
        mandatory true;
        description
            "Selected output power.";
        reference "ETSI EN 302 217-1";
    }
}
container atpc {
    description
        "Automatic Transmit Power Control (ATPC).";
    reference "ETSI EN 302 217-1";

    leaf maximum-nominal-power {
        type power {
            range "-99..99";
        }
        units "dBm";
        mandatory true;
        description
            "Selected maximum output power. Minimum output
            power is the same as the system capability,
            available-min-output-power.";
        reference "ETSI EN 302 217-1";
    }

    leaf atpc-lower-threshold {
        type power {
            range "-99..-20";
        }
        units "dBm";
        must "current() <= ../atpc-upper-threshold";
        mandatory true;
        description
            "The lower threshold for the input power at far-end
            used in the ATPC mode.";
        reference "ETSI EN 302 217-1";
    }

    leaf atpc-upper-threshold {
        type power {
            range "-99..-20";
        }
        units "dBm";
        mandatory true;
        description
            "The upper threshold for the input power at far-end
            used in the ATPC mode.";
        reference "ETSI EN 302 217-1";
    }
}
```

```
    }
  }
  mandatory true;
  description
    "A choice of Remote Transmit Power Control (RTPC)
    or Automatic Transmit Power Control (ATPC).";
}

leaf actual-transmitted-level {
  type power {
    range "-99..99";
  }
  units "dBm";
  config false;
  description
    "Actual transmitted power level (0.1 dBm resolution).";
  reference "ETSI EN 301 129";
}

leaf actual-received-level {
  type power {
    range "-99..-20";
  }
  units "dBm";
  config false;
  description
    "Actual received power level (0.1 dBm resolution).";
  reference "ETSI EN 301 129";
}

choice coding-modulation-mode {
  container single {
    description "A single modulation order only.";
    reference "ETSI EN 302 217-1";

    leaf selected-cm {
      type identityref {
        base mw-types:coding-modulation;
      }
      mandatory true;
      description
        "Selected the single coding/modulation.";
    }
  }

  container adaptive {
    description "Adaptive coding/modulation.";
    reference "ETSI EN 302 217-1";
  }
}
```

```
    leaf selected-min-acm {
      type identityref {
        base mw-types:coding-modulation;
      }
      mandatory true;
      description
        "Selected minimum coding/modulation.
        Adaptive coding/modulation shall not go
        below this value.";
    }

    leaf selected-max-acm {
      type identityref {
        base mw-types:coding-modulation;
      }
      mandatory true;
      description
        "Selected maximum coding/modulation.
        Adaptive coding/modulation shall not go
        above this value.";
    }
  }
  mandatory true;
  description
    "A selection of single or
    adaptive coding/modulation mode.";
}

leaf actual-tx-cm {
  type identityref {
    base mw-types:coding-modulation;
  }
  config false;
  description
    "Actual coding/modulation in transmitting direction.";
}

leaf actual-snr {
  type decimal64 {
    fraction-digits 1;
    range "0..99";
  }
  units "dB";
  config false;
  description
    "Actual signal to noise plus interference ratio.
    (0.1 dB resolution).";
}
```



```
leaf actual-xpi {
  if-feature xpig;
  type decimal64 {
    fraction-digits 1;
    range "0..99";
  }
  units "dB";
  config false;
  description
    "The actual carrier to cross-polar interference.
    Only valid if XPIC is enabled. (0.1 dB resolution).";
  reference "ETSI TR 102 311";
}

container ct-performance-thresholds {
  description
    "Specification of thresholds for when alarms should
    be sent and cleared for various performance counters.";

  leaf received-level-alarm-threshold {
    type power {
      range "-99..-20";
    }
    units "dBm";
    default "-99";
    description
      "An alarm is sent when the received power level is
      below the specified threshold.";
    reference "ETSI EN 301 129";
  }

  leaf transmitted-level-alarm-threshold {
    type power {
      range "-99..99";
    }
    units "dBm";
    default "-99";
    description
      "An alarm is sent when the transmitted power level
      is below the specified threshold.";
    reference "ETSI EN 301 129";
  }

  leaf ber-alarm-threshold {
    type enumeration {
      enum "1e-9" {
        description "Threshold at 1e-9 (10^-9).";
      }
    }
  }
}
```

```
    enum "1e-8" {
        description "Threshold at 1e-8 (10^-8).";
    }
    enum "1e-7" {
        description "Threshold at 1e-7 (10^-7).";
    }
    enum "1e-6" {
        description "Threshold at 1e-6 (10^-6).";
    }
    enum "1e-5" {
        description "Threshold at 1e-5 (10^-5).";
    }
    enum "1e-4" {
        description "Threshold at 1e-4 (10^-4).";
    }
    enum "1e-3" {
        description "Threshold at 1e-3 (10^-3).";
    }
    enum "1e-2" {
        description "Threshold at 1e-2 (10^-2).";
    }
    enum "1e-1" {
        description "Threshold at 1e-1 (10^-1).";
    }
}
default "1e-6";
description
    "Specification of at which BER an alarm should
    be raised.";
reference "ETSI EN 302 217-1";
}
}

leaf if-loop {
    type enumeration {
        enum disabled {
            description "Disables the IF Loop.";
        }
        enum client {
            description
                "Loops the signal back to the client side.";
        }
        enum radio {
            description
                "Loops the signal back to the radio side.";
        }
    }
    default "disabled";
}
```

```
    description
      "Enable (client/radio) or disable (disabled)
       the IF loop, which loops the signal back to
       the client side or the radio side.";
  }

  leaf rf-loop {
    type enumeration {
      enum disabled {
        description "Disables the RF Loop.";
      }
      enum client {
        description
          "Loops the signal back to the client side.";
      }
      enum radio {
        description
          "Loops the signal back to the radio side.";
      }
    }
    default "disabled";
    description
      "Enable (client/radio) or disable (disabled)
       the RF loop, which loops the signal back to
       the client side or the radio side.";
  }

  container capabilities {
    config false;
    description
      "Capabilities of the installed equipment and
       some selected configurations.";

    leaf min-tx-frequency {
      type uint32;
      units "kHz";
      description
        "Minimum Tx frequency possible to use.";
    }

    leaf max-tx-frequency {
      type uint32;
      units "kHz";
      description
        "Maximum Tx frequency possible to use.";
    }

    leaf min-rx-frequency {
```

```
    type uint32;
    units "kHz";
    description
        "Minimum Rx frequency possible to use.";
}

leaf max-rx-frequency {
    type uint32;
    units "kHz";
    description
        "Maximum Tx frequency possible to use.";
}

leaf minimum-power {
    type power;
    units "dBm";
    description
        "The minimum output power supported.";
    reference "ETSI EN 302 217-1";
}

leaf maximum-available-power {
    type power;
    units "dBm";
    description
        "The maximum output power supported.";
    reference "ETSI EN 302 217-1";
}

leaf available-min-acm {
    type identityref {
        base mw-types:coding-modulation;
    }
    description
        "Minimum coding-modulation possible to use.";
}

leaf available-max-acm {
    type identityref {
        base mw-types:coding-modulation;
    }
    description
        "Maximum coding-modulation possible to use.";
}
}

container error-performance-statistics {
    config false;
```

```
description
  "ITU-T G.826 error performance statistics relevant for
  a microwave/millimeter wave carrier.";

leaf bbe {
  type yang:counter32;
  units "number of block errors";
  description
    "Number of Background Block Errors (BBE). A BBE is an
    errored block not occurring as part of an SES.
    Discontinuities in the value of this counter can occur
    at re-initialization of the management system and at
    other times as indicated by the value of
    'discontinuity-time' in ietf-interfaces.";
  reference "ITU-T G.826";
}

leaf es {
  type yang:counter32;
  units "seconds";
  description
    "Number of Errored Seconds (ES).
    An ES is a one-second period with one or more errored
    blocks or at least one defect.
    Discontinuities in the value of this counter can occur
    at re-initialization of the management system and at
    other times as indicated by the value of
    'discontinuity-time' in ietf-interfaces.";
  reference "ITU-T G.826";
}

leaf ses {
  type yang:counter32;
  units "seconds";
  description
    "Number of Severely Errored Seconds (SES).
    SES is a one-second period which contains
    equal or more than 30% errored blocks or at least
    one defect. SES is a subset of ES.
    Discontinuities in the value of this counter can occur
    at re-initialization of the management system and at
    other times as indicated by the value of
    'discontinuity-time' in ietf-interfaces.";
  reference "ITU-T G.826";
}

leaf uas {
  type yang:counter32;
```

```
    units "seconds";
    description
      "Number of Unavailable Seconds (UAS), that is, the
       total time that the node has been unavailable.
       Discontinuities in the value of this counter can occur
       at re-initialization of the management system and at
       other times as indicated by the value of
       'discontinuity-time' in ietf-interfaces.";
    reference "ITU-T G.826";
  }
}

container radio-performance-statistics {
  config false;
  description
    "ETSI EN 301 129 radio physical interface statistics relevant
     for a carrier termination.";

  leaf min-rltm {
    type power {
      range "-99..-20";
    }
    units "dBm";
    description
      "Minimum received power level.
       Discontinuities in the value of this counter can occur
       at re-initialization of the management system and at
       other times as indicated by the value of
       'discontinuity-time' in ietf-interfaces.";
    reference "ETSI EN 301 129";
  }

  leaf max-rltm {
    type power {
      range "-99..-20";
    }
    units "dBm";
    description
      "Maximum received power level.
       Discontinuities in the value of this counter can occur
       at re-initialization of the management system and at
       other times as indicated by the value of
       'discontinuity-time' in ietf-interfaces.";
    reference "ETSI EN 301 129";
  }

  leaf min-tltm {
    type power {
```

```
        range "-99..99";
    }
    units "dBm";
    description
        "Minimum transmitted power level.
        Discontinuities in the value of this counter can occur
        at re-initialization of the management system and at
        other times as indicated by the value of
        'discontinuity-time' in ietf-interfaces.";
    reference "ETSI EN 301 129";
}

leaf max-tlrm {
    type power {
        range "-99..99";
    }
    units "dBm";
    description
        "Maximum transmitted power level.
        Discontinuities in the value of this counter can occur
        at re-initialization of the management system and at
        other times as indicated by the value of
        'discontinuity-time' in ietf-interfaces.";
    reference "ETSI EN 301 129";
}
}

/*
 * Radio Link Protection Groups
 */

container radio-link-protection-groups {
    description
        "Configuration of radio link protected groups (1+1) of
        carrier terminations in a radio link. More than one
        protected group per radio-link-terminal is allowed.";

    uses ifprot:protection-groups {

        refine protection-group/members {
            must "derived-from-or-self(/if:interfaces/if:interface"
                + "[if:name = current()]"
                + "/if:type, 'ianaift:carrier-termination')" {
                description
                    "The type of a protection member must be
                    'carrier-termination'.";
            }
        }
    }
}
```

```
    }

    refine protection-group/working-entity {
      must "derived-from-or-self(/if:interfaces/if:interface"
        + "[if:name = current()]"
        + "/if:type, 'ianaift:carrier-termination') " {
        description
          "The type of a working-entity must be
           'carrier-termination'.";
      }
    }
  }
}

/*
 * XPIC & MIMO groups - Configuration data nodes
 */

container xp-pic-pairs {
  if-feature xp-pic;
  description
    "Configuration of carrier termination pairs
     for operation in XPIC mode.";
  reference "ETSI TR 102 311";

  list xp-pic-pair {
    key "name";
    description
      "List of carrier termination pairs in XPIC mode.";

    leaf name {
      type string;
      description
        "Name used for identification of the XPIC pair.";
    }

    leaf enabled {
      type boolean;
      default "false";
      description
        "Enable(true)/disable(false) XPIC";
    }

    leaf-list members {
      type if:interface-ref;
      must "derived-from-or-self(/if:interfaces/if:interface"
        + "[if:name = current()]"
        + "/if:type, 'ianaift:carrier-termination') " {
```



```
        description
            "The type of a member must be 'carrier-termination'.";
    }
    min-elements 2;
    max-elements 2;
    description
        "Association to XPIC pairs used in the radio link
        terminal.";
    }
}
}

container mimo-groups {
    if-feature mimo;
    description
        "Configuration of carrier terminations
        for operation in MIMO mode.";
    reference "ETSI TR 102 311";

    list mimo-group {
        key "name";
        description
            "List of carrier terminations in MIMO mode.";

        leaf name {
            type string;
            description
                "Name used for identification of the MIMO group.";
        }

        leaf enabled {
            type boolean;
            default "false";
            description
                "Enable(true)/disable(false) MIMO";
        }

        leaf-list members {
            type if:interface-ref;
            must "derived-from-or-self(/if:interfaces/if:interface"
                + "[if:name = current()]"
                + "/if:type, 'ianaift:carrier-termination')";
            description
                "The type of a member must be 'carrier-termination'.";
        }

        min-elements 2;
        description

```

```
        "Association to a MIMO group if used in the radio
          link terminal.";
      }
    }
  }
}

<CODE ENDS>
```

## 5. Interface Protection YANG Module

The data nodes for management of the interface protection functionality is broken out from the Microwave Radio Link Module into a separate and generic YANG data module in order to make it available also for other interface types.

This module imports modules from [RFC8343], and it references [G.808.1].

```
<CODE BEGINS> file "ietf-interface-protection@2018-11-28.yang"

module ietf-interface-protection {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-interface-protection";
  prefix ifprot;

  import ietf-interfaces {
    prefix if;
    reference "RFC8343";
  }

  organization
    "Internet Engineering Task Force (IETF) CCAMP WG";
  contact
    "WG List: <mailto:ccamp@ietf.org>"

  ID-draft editors:
    Jonas Ahlberg (jonas.ahlberg@ericsson.com);
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    Marko Vaupotic (Marko.Vaupotic@aviatnet.com);

  description
    "This is a module for the entities in
    a generic interface protection mechanism."
```

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```
revision 2018-11-28 {
  description "Initial revision.";
  reference "RFC XXXX: A YANG Data Model for Microwave Radio Link";
}

/*
 * Protection architecture type identities
 */

identity protection-architecture-type {
  description
    "protection architecture type";
  reference "ITU-T G.808.1";
}

identity one-plus-one-type {
  base protection-architecture-type;
  description
    "1+1, One interface protects
    another one interface.";
  reference "ITU-T G.808.1";
}

identity one-to-n-type {
  base protection-architecture-type;
  description
    "1:N, One interface protects
    n other interfaces.";
  reference "ITU-T G.808.1";
}

/*
```

```
* Protection states identities
*/

identity protection-states {
  description
    "Identities describing the status of the protection,
    in a group of interfaces configured in
    a protection mode.";
}

identity unprotected {
  base protection-states;
  description "Not protected";
}

identity protected {
  base protection-states;
  description "Protected";
}

identity unable-to-protect {
  base protection-states;
  description "Unable to protect";
}

/*
 * Protection Groups
 */

grouping protection-groups {
  description
    "Configuration of protected groups (1+1) of interfaces
    providing protection for each other. More than one protected
    group per higher-layer-interface is allowed.";

  list protection-group {
    key "name";
    description
      "List of protected groups of interfaces
      in a higher-layer-interface.";

    leaf name {
      type string;
      description
        "Name used for identification of the protection group";
    }

    leaf protection-architecture-type {
```

```
    type identityref {
      base protection-architecture-type;
    }
    default "ifprot:one-plus-one-type";
    description
      "The type of protection architecture used, e.g. one
       interface protecting one or several other interfaces.";
    reference "ITU-T G.808.1";
  }

  leaf-list members {
    type if:interface-ref;
    min-elements 2;
    description
      "Association to a group of interfaces configured for
       protection and used by a higher-layer-interface.";
  }

  leaf operation-type {
    type enumeration {
      enum "non-revertive" {
        description
          "In non revertive operation, the traffic does not
           return to the working interface if the switch requests
           are terminated.";
        reference "ITU-T G.808.1";
      }
      enum "revertive" {
        description
          "In revertive operation, the traffic always
           returns to (or remains on) the working interface
           if the switch requests are terminated.";
        reference "ITU-T G.808.1";
      }
    }
    default "non-revertive";
    description
      "The type of protection operation, i.e. revertive
       or non-revertive operation.";
  }

  leaf-list working-entity {
    when "../operation-type = 'revertive'";
    type if:interface-ref;
    min-elements 1;
    description
      "The interfaces over which the traffic normally should
       be transported over when there is no need to use the
```

```
        protecting interface.";
    }

    leaf revertive-wait-to-restore {
        when "../operation-type = 'revertive'";
        type uint16;
        units "seconds";
        default "0";
        description
            "The time to wait before switching back to the working
            interface if operation-type is revertive.";
        reference "ITU-T G.808.1";
    }

    leaf hold-off-timer {
        type uint16;
        units "milliseconds";
        default "0";
        description
            "Time interval after the detection of a fault and its
            confirmation as a condition requiring the protection
            switching procedure.";
        reference "ITU-T G.808.1";
    }

    leaf status {
        type identityref {
            base protection-states;
        }
        config false;
        description
            "Status of the protection, in a group of interfaces
            configured in a protection mode.";
        reference "ITU-T G.808.1";
    }

    action manual-switch-working {
        description
            "A switch action initiated by an operator command.
            It switches normal traffic signal to the working
            transport entity.";
        reference "ITU-T G.808.1";
    }

    action manual-switch-protection {
        description
            "A switch action initiated by an operator command.
            It switches normal traffic signal to the protection
```

```
        transport entity.";
        reference "ITU-T G.808.1";
    }

    action forced-switch {
        description
            "A switch action initiated by an operator command.
            It switches normal traffic signal to the protection
            transport entity and forces it to remain on that
            entity even when criteria for switching back to
            the original entity are fulfilled.";
        reference "ITU-T G.808.1";
    }

    action lockout-of-protection {
        description
            "A switch action temporarily disables access to the
            protection transport entity for all signals.";
        reference "ITU-T G.808.1";
    }

    action freeze {
        description
            "A switch action temporarily prevents any switch action
            to be taken and, as such, freezes the current state.
            Until the freeze is cleared, additional near-end external
            commands are rejected and fault condition changes and
            received APS messages are ignored..";
        reference "ITU-T G.808.1";
    }

    action exercise {
        description
            "A switch action to test if the APS communication is
            operating correctly. It is lower priority than any 'real'
            switch request..";
        reference "ITU-T G.808.1";
    }

    action clear {
        description
            "An action clears all switch commands.";
        reference "ITU-T G.808.1";
    }
}
}
```

<CODE ENDS>

## 6. Microwave Types YANG Module

This module defines a collection of common data types using the YANG data modeling language. These common types are designed to be imported by other modules defined in the microwave area.

<CODE BEGINS> file "ietf-microwave-types@2018-11-28.yang"

```
module ietf-microwave-types {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-microwave-types";
  prefix mw-types;

  organization
    "Internet Engineering Task Force (IETF) CCAMP WG";
  contact
    "WG List: <mailto:ccamp@ietf.org>";

  ID-draft editors:
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    Xi Li (Xi.Li@neclab.eu);
    Daniela Spreafico (daniela.spreafico@nokia.com)
    Marko Vaupotic (Marko.Vaupotic@aviatnet.com)";

  description
    "This module contains a collection of YANG data types
    considered generally useful for microwave interfaces.

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    authors of the code. All rights reserved.

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    (http://trustee.ietf.org/license-info).

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

    Copyright (c) 2018 IETF Trust and the persons identified as
    authors of the code. All rights reserved.";
```



```
revision 2018-11-28 {
  description "Initial revision.";
  reference "RFC XXXX: A YANG Data Model for Microwave Radio Link";
}

/*
 * Radio-link-terminal mode identities
 */

identity rlt-mode {
  description
    "A description of the mode in which the radio link
    terminal is configured. The format is X plus Y.
    X represent the number of bonded carrier terminations.
    Y represent the number of protecting carrier
    terminations.";
}

identity one-plus-zero {
  base rlt-mode;
  description
    "1 carrier termination only.";
}

identity one-plus-one {
  base rlt-mode;
  description
    "1 carrier termination
    and 1 protecting carrier termination.";
}

identity two-plus-zero {
  base rlt-mode;
  description
    "2 bonded carrier terminations.";
}

/*
 * Coding and modulation identities
 */

identity coding-modulation {
  description
    "The coding and modulation schemes.";
}

identity half-bpsk {
  base coding-modulation;
}
```

```
    description
      "Half BPSK coding and modulation scheme.";
  }

  identity half-bpsk-strong {
    base half-bpsk;
    description
      "Half BPSK strong coding and modulation scheme.";
  }

  identity half-bpsk-light {
    base half-bpsk;
    description
      "Half BPSK light coding and modulation scheme.";
  }

  identity bpsk {
    base coding-modulation;
    description
      "BPSK coding and modulation scheme.";
  }

  identity bpsk-strong {
    base bpsk;
    description
      "BPSK strong coding and modulation scheme.";
  }

  identity bpsk-light {
    base bpsk;
    description
      "BPSK light coding and modulation scheme.";
  }

  identity qpsk {
    base coding-modulation;
    description
      "QPSK coding and modulation scheme.";
  }

  identity qam-4 {
    base coding-modulation;
    description
      "4 QAM coding and modulation scheme.";
  }

  identity qam-4-strong {
    base qam-4;
```

```
    description
      "4 QAM strong coding and modulation scheme.";
  }

  identity qam-4-light {
    base qam-4;
    description
      "4 QAM light coding and modulation scheme.";
  }

  identity qam-16 {
    base coding-modulation;
    description
      "16 QAM coding and modulation scheme.";
  }

  identity qam-16-strong {
    base qam-16;
    description
      "16 QAM strong coding and modulation scheme.";
  }

  identity qam-16-light {
    base qam-16;
    description
      "16 QAM light coding and modulation scheme.";
  }

  identity qam-32 {
    base coding-modulation;
    description
      "32 QAM coding and modulation scheme.";
  }

  identity qam-32-strong {
    base qam-32;
    description
      "32 QAM strong coding and modulation scheme.";
  }

  identity qam-32-light {
    base qam-32;
    description
      "32 QAM light coding and modulation scheme.";
  }

  identity qam-64 {
    base coding-modulation;
```

```
    description
      "64 QAM coding and modulation scheme.";
  }

  identity qam-64-strong {
    base qam-64;
    description
      "64 QAM strong coding and modulation scheme.";
  }

  identity qam-64-light {
    base qam-64;
    description
      "64 QAM light coding and modulation scheme.";
  }

  identity qam-128 {
    base coding-modulation;
    description
      "128 QAM coding and modulation scheme.";
  }

  identity qam-128-strong {
    base qam-128;
    description
      "128 QAM strong coding and modulation scheme.";
  }

  identity qam-128-light {
    base qam-128;
    description
      "128 QAM light coding and modulation scheme.";
  }

  identity qam-256 {
    base coding-modulation;
    description
      "256 QAM coding and modulation scheme.";
  }

  identity qam-256-strong {
    base qam-256;
    description
      "256 QAM strong coding and modulation scheme.";
  }

  identity qam-256-light {
    base qam-256;
```

```
    description
      "256 QAM light coding and modulation scheme.";
  }

  identity qam-512 {
    base coding-modulation;
    description
      "512 QAM coding and modulation scheme.";
  }

  identity qam-512-strong {
    base qam-512;
    description
      "512 QAM strong coding and modulation scheme.";
  }

  identity qam-512-light {
    base qam-512;
    description
      "512 QAM light coding and modulation scheme.";
  }

  identity qam-1024 {
    base coding-modulation;
    description
      "1024 QAM coding and modulation scheme.";
  }

  identity qam-1024-strong {
    base qam-1024;
    description
      "1024 QAM strong coding and modulation scheme.";
  }

  identity qam-1024-light {
    base qam-1024;
    description
      "1024 QAM light coding and modulation scheme.";
  }

  identity qam-2048 {
    base coding-modulation;
    description
      "2048 QAM coding and modulation scheme.";
  }

  identity qam-2048-strong {
    base qam-2048;
```

```
    description
      "2048 QAM strong coding and modulation scheme.";
  }

  identity qam-2048-light {
    base qam-2048;
    description
      "2048 QAM light coding and modulation scheme.";
  }

  identity qam-4096 {
    base coding-modulation;
    description
      "4096 QAM coding and modulation scheme.";
  }

  identity qam-4096-strong {
    base qam-4096;
    description
      "4096 QAM strong coding and modulation scheme.";
  }

  identity qam-4096-light {
    base qam-4096;
    description
      "4096 QAM light coding and modulation scheme.";
  }

  /*
   * TDM-type identities
   */

  identity tdm-type {
    description
      "A description of the type of TDM connection,
       also indicating the supported capacity of the
       connection.";
  }

  identity E1 {
    base tdm-type;
    description
      "E1 connection, 2.048 Mbit/s.";
  }

  identity STM-1 {
    base tdm-type;
    description
```

```
        "STM-1 connection, 155.52 Mbit/s.";
    }
}

<CODE ENDS>
```

## 7. Security Considerations

The YANG modules specified in this document define schemas for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in these YANG modules that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. These are the subtrees and data nodes and their sensitivity/vulnerability:

Interfaces of type radio-link-terminal:

```
/if:interfaces/if:interface/mode,
/if:interfaces/if:interface/carrier-terminations,
/if:interfaces/if:interface/rlp-groups,
/if:interfaces/if:interface/xpic-pairs,
/if:interfaces/if:interface/mimo-groups, and
/if:interfaces/if:interface/tdm-connections:
```

These data nodes represent the configuration of the radio-link-terminal and they need to match the configuration of the radio-link-terminal on the other side of the radio link. Unauthorized access to these data nodes could interrupt the ability to forward traffic.

Interfaces of type carrier-termination:

```
/if:interfaces/if:interface/carrier-id,  
/if:interfaces/if:interface/tx-enabled,  
/if:interfaces/if:interface/tx-frequency,  
/if:interfaces/if:interface/rx-frequency,  
/if:interfaces/if:interface/duplex-distance,  
/if:interfaces/if:interface/channel-separation,  
/if:interfaces/if:interface/rtpc/maximum-nominal-power,  
/if:interfaces/if:interface/atpc/maximum-nominal-power,  
/if:interfaces/if:interface/atpc/atpc-lower-threshold,  
/if:interfaces/if:interface/atpc/atpc-upper-threshold,  
/if:interfaces/if:interface/single/selected-cm,  
/if:interfaces/if:interface/adaptive/selected-min-acm,  
/if:interfaces/if:interface/adaptive/selected-max-acm,  
/if:interfaces/if:interface/if-loop, and  
/if:interfaces/if:interface/rf-loop:
```

These data nodes represent the configuration of the carrier-termination and they need to match the configuration of the carrier-termination on the other side of the carrier. Unauthorized access to these data nodes could interrupt the ability to forward traffic.

Radio link protection:

```
/radio-link-protection-groups/protection-group:
```

This data node represents the configuration of the protection of carrier terminations. Unauthorized access to this data node could interrupt the ability to forward traffic or remove the ability to perform a necessary protection switch.

XPIC:

```
/xp-pic-pairs:
```

This data node represents the XPIC configuration of a pair carriers. Unauthorized access to this data node could interrupt the ability to forward traffic.

MIMO:

```
/mimo-groups:
```



This data node represents the MIMO configuration of multiple carriers. Unauthorized access to this data node could interrupt the ability to forward traffic.

The security considerations of [RFC8343] also apply to this document.

## 8. IANA Considerations

It is proposed that IANA should assign new URIs from the "IETF XML Registry" [RFC3688] as follows:

URI: urn:ietf:params:xml:ns:yang:ietf-microwave-radio-link  
Registrant Contact: The IESG  
XML: N/A; the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-interface-protection  
Registrant Contact: The IESG  
XML: N/A; the requested URI is an XML namespace.

URI: urn:ietf:params:xml:ns:yang:ietf-microwave-types  
Registrant Contact: The IESG  
XML: N/A; the requested URI is an XML namespace.

It is proposed that IANA should record YANG module names in the "YANG Module Names" registry [RFC6020] as follows:

Name: ietf-microwave-radio-link  
Maintained by IANA?: N  
Namespace: urn:ietf:params:xml:ns:yang:ietf-microwave-radio-link  
Prefix: mrl  
Reference: RFC XXXX

Name: ietf-interface-protection  
Maintained by IANA?: N  
Namespace: urn:ietf:params:xml:ns:yang:ietf-interface-protection  
Prefix: ifprot  
Reference: RFC XXXX

Name: ietf-microwave-types  
Maintained by IANA?: N  
Namespace: urn:ietf:params:xml:ns:yang:ietf-microwave-types  
Prefix: mw-types  
Reference: RFC XXXX

It is proposed that IANA should register a new IANAifType TBD1 for the interface type radio-link-terminal and a new IANAifType TBD2 for the interface type carrier-termination at [IFTYPE-IANA-REGISTRY].

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#### Appendix A. Example: 1+0 and 2+0 configuration instances

This section gives simple examples of 1+0 and 2+0 instance using the YANG module defined in this draft. The examples are not intended as a complete module for 1+0 and 2+0 configuration.

## A.1. 1+0 instance

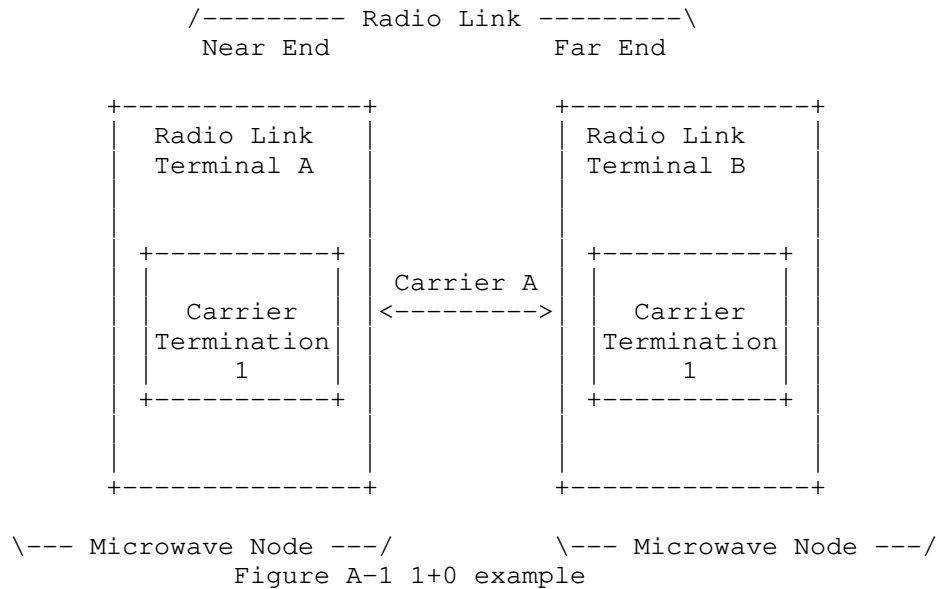


Figure A-1 shows a 1+0 example. The following instance shows the 1+0 configuration of Near End node.

```
"interface": [
  {
    "name": "RLT-A",
    "description": "Radio Link Terminal A",
    "type": "radio-link-terminal",
    "id": "RLT-A",
    "mode": "one-plus-zero",
    "carrier-terminations": [
      "RLT-A:CT-1"
    ],
    "tdm-connections": [
      "tdm-type": "E1",
      "tdm-connections": "4"
    ]
  },
  {
    "name": "RLT-A:CT-1",
    "description": "Carrier Termination 1",
    "type": "carrier-termination",
    "carrier-id": "A",
```

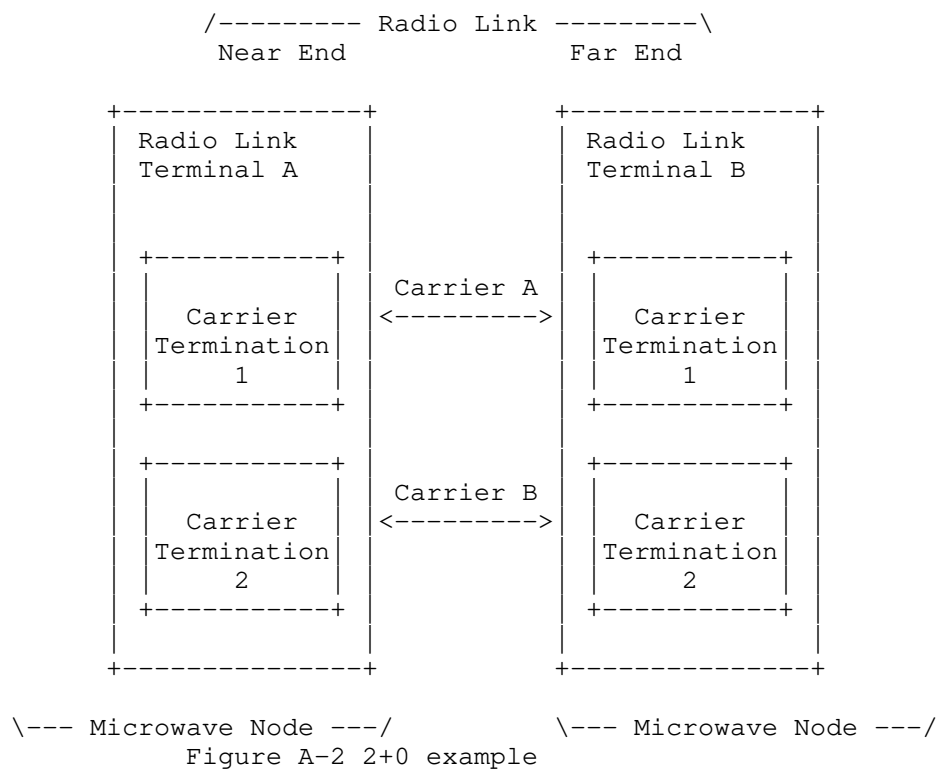
```

    "tx-enabled": true,
    "tx-frequency": 10728000,
    "duplex-distance": 644000,
    "channel-separation": 28,
    "polarization": not-specified,
    "rtpc": {
      "maximum-nominal-power": 20
    },
    "single": {
      "selected-cm": "qam-512"
    }
  }
]

```

#### A.2. 2+0 instance

Figure A-2 shows a 2+0 example.



The following instance shows the 2+0 configuration of Near End node.

```
"interface": [
  {
    "name": "RLT-A",
    "description": "Radio Link Terminal A",
    "type": "radio-link-terminal",
    "id": "RLT-A",
    "mode": "two-plus-zero",
    "carrier-terminations": [
      "RLT-A:CT-1",
      "RLT-A:CT-2"
    ],
    "tdm-connections": [
      "tdm-type": "E1",
      "tdm-connections": "4"
    ]
  },
  {
    "name": "RLT-A:CT-1",
    "description": "Carrier Termination 1",
    "type": "carrier-termination",
    "carrier-id": "A",
    "tx-enabled": true,
    "tx-frequency": 10728000,
    "duplex-distance": 644000,
    "channel-separation": 28,
    "polarization": not-specified,
    "rtpc": {
      "maximum-nominal-power": 20
    },
    "single": {
      "selected-cm": "qam-512"
    }
  },
  {
    "name": "RLT-A:CT-2",
    "description": "Carrier Termination 2",
    "type": "carrier-termination",
    "carrier-id": "B",
    "tx-enabled": true,
    "tx-oper-status": on,
    "tx-frequency": 10618000,
    "duplex-distance": 644000,
    "channel-separation": 28,
```

```
    "polarization": not-specified,
    "rtpc": {
      "maximum-nominal-power": 20
    },
    "single": {
      "selected-cm": "qam-512"
    }
  }
]
```

### A.3. 2+0 XPIC instance

The following instance shows the XPIC configuration of Near End node.

```
"interface": [
  {
    "name": "RLT-A",
    "description": "Radio Link Terminal A",
    "type": "radio-link-terminal",
    "id": "RLT-A",
    "mode": "two-plus-zero",
    "carrier-terminations": [
      "RLT-A:CT-1",
      "RLT-A:CT-2"
    ],
    "xplic-pairs": [
      "RLT-A:CT-1",
      "RLT-A:CT-2"
    ],
    "tdm-connections": [
      "tdm-type": "E1",
      "tdm-connections": "4"
    ]
  },
  {
    "name": "RLT-A:CT-1",
    "description": "Carrier Termination 1",
    "type": "carrier-termination",
    "carrier-id": "A",
    "tx-enabled": true,
    "tx-frequency": 10728000,
    "duplex-distance": 644000,
    "channel-separation": 28,
    "polarization": not-specified,
    "rtpc": {
```



```
        "maximum-nominal-power": 20
      },
      "single": {
        "selected-cm": "qam-512"
      }
    },
    {
      "name": "RLT-A:CT-2",
      "description": "Carrier Termination 2",
      "type": "carrier-termination",
      "carrier-id": "B",
      "tx-enabled": true,
      "tx-oper-status": on,
      "tx-frequency": 10618000,
      "duplex-distance": 644000,
      "channel-separation": 28,
      "polarization": not-specified,
      "rtpc": {
        "maximum-nominal-power": 20
      },
      "single": {
        "selected-cm": "qam-512"
      }
    }
  ]
}
```

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A YANG Data Model for Optical Transport Network Topology  
draft-ietf-ccamp-otn-topo-yang-00

## Abstract

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed from equipments utilizing any of a number of different transport technologies such as the evolving Optical Transport Networks (OTN) or packet transport as provided by the MPLS-Transport Profile (MPLS-TP).

This draft describes a YANG data model to describe the topologies of an Optical Transport Network (OTN). It is independent of control plane protocols and captures topological and resource related information pertaining to OTN. This model enables clients, which interact with a transport domain controller via a REST interface, for OTN topology related operations such as obtaining the relevant topology resource information.

## Requirements Language

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

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#### 1. Introduction

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed of equipments utilizing any of a number of different transport technologies such as the Optical

Transport Networks (OTN) or packet transport as provided by the MPLS-Transport Profile (MPLS-TP).

This document defines a data model of an OTN network topology, using YANG [RFC6020]. The model can be used by an application exposing to a transport controller via a REST interface. Furthermore, it can be used by an application for the following purposes (but not limited to):

- o To obtain a whole view of the network topology information of its interest;
- o To receive notifications with regard to the information change of the OTN topology;
- o To enforce the establishment and update of a network topology with the characteristic specified in the data model, e.g., by a client controller;

The YANG model defined in this draft is independent of control plane protocols and captures topology related information pertaining to an Optical Transport Networks (OTN)-electrical layer, as the scope specified by [RFC7062] and [RFC7138]. Furthermore, it is not a stand-alone model, but augmenting from the TE topology YANG model defined in [I-D.ietf-teas-yang-te-topo].

Optical network technologies, including fixed Dense Wavelength Switched Optical Network (WSON) and flexible optical networks (a.k.a., flexi-grid networks), are covered in [I-D.ietf-ccamp-wson-yang] and [I-D.vergara-ccamp-flexigrid-yang], respectively.

## 2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this draft is defined in [I-D.ietf-netmod-rfc6087bis]. They are provided below for reference.

- o Brackets "[" and "]" enclose list keys.
- o Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- o Symbols after data node names: "?" means an optional node, "!" means a presence container, and "\*" denotes a list and leaf-list.

- o Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- o Ellipsis ("...") stands for contents of subtrees that are not shown.

### 3. YANG Data Model for OTN Topology

#### 3.1. the YANG Tree

```

module: ietf-otn-topology
augment /nd:networks/nd:network/nd:network-types/tet:te-topology:
  +--rw otn-topology!
augment /nd:networks/nd:network:
  +--rw name? string
augment /nd:networks/nd:network/nd:node:
  +--rw name? string
augment /nd:networks/nd:network/lnk:link/tet:te/tet:config:
  +--rw available-odu-info* [priority]
  |   +--rw priority      uint8
  |   +--rw odulist* [odu-type]
  |       +--rw odu-type  identityref
  |       +--rw number?   uint16
  +--rw distance?        uint32
augment /nd:networks/nd:network/lnk:link/tet:te/tet:state:
  +--ro available-odu-info* [priority]
  |   +--ro priority      uint8
  |   +--ro odulist* [odu-type]
  |       +--ro odu-type  identityref
  |       +--ro number?   uint16
  +--ro distance?        uint32
augment /nd:networks/nd:network/nd:node/lnk:termination-point
/tet:te/tet:config:
  +--rw client-facing?          empty
  +--rw tpn?                    uint16
  +--rw tsg?                    identityref
  +--rw protocol-type?          identityref
  +--rw adaptation-type?        adaptation-type
  +--rw sink-adapt-active?      boolean
  +--rw source-adapt-active?    boolean
  +--rw tributary-slots
  |   +--rw values*            uint8
  +--rw supported-payload-types* [index]
  |   +--rw index              uint16
  |   +--rw payload-type?      string
augment /nd:networks/nd:network/nd:node/lnk:termination-point/
tet:te/tet:state:

```

```

+--ro client-facing?          empty
+--ro tpn?                    uint16
+--ro tsq?                    identityref
+--ro protocol-type?          identityref
+--ro adaptation-type?        adaptation-type
+--ro sink-adapt-active?      boolean
+--ro source-adapt-active?    boolean
+--ro tributary-slots
|   +--ro values*             uint8
+--ro supported-payload-types* [index]
    +--ro index                uint16
    +--ro payload-type?       string

```

### 3.2. Explanation of the OTN Topology Data Model

As can be seen, from the data tree shown in Section 3.1, the YANG module presented in this draft augments from a more generic Traffic Engineered (TE) network topology data model, i.e., the `ietf-te-topology.yang` as specified in [I-D.ietf-teas-yang-te-topol]. The entities and their attributes, such as node, termination points and links, are still applicable for describing an OTN topology and the model presented in this draft only specifies with technology-specific attributes/information. For example, if the data plane complies with ITU-T G.709 (2012) standards, the switching-capability and encoding attributes MUST be filled as OTN-TDM and G.709 ODUk(Digital Path) respectively.

Note the model in this draft re-uses some attributes defined in `ietf-transport-types.yang`, which is specified in [I-D.sharma-ccamp-otn-tunnel-model].

One of the main augmentations in this model is that it allows to specify the type of ODU container and the number a link can support per priority level. For example, for a ODU3 link, it may advertise 32\*ODU0, 16\*ODU1, 4\*ODU2 available, assuming only a single priority level is supported. If one of ODU2 resource is taken to establish a ODU path, then the availability of this ODU link is updated as 24\*ODU0, 12\*ODU1, 3\*ODU2 available. If there are equipment hardware limitations, then a subset of potential ODU type SHALL be advertised. For instance, an ODU3 link may only support 4\*ODU2.

### 3.3. The YANG Code

```

<CODE BEGINS> file "ietf-otn-topology@2017-04-25.yang"

module ietf-otn-topology {

```

```
yang-version 1.1;

namespace "urn:ietf:params:xml:ns:yang:ietf-otn-topology";
prefix "otntopo";

import ietf-network {
  prefix "nd";
}

import ietf-network-topology {
  prefix "lnk";
}

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

import ietf-transport-types {
  prefix "tran-types";
}

organization
  "Internet Engineering Task Force (IETF) CCAMP WG";
contact
  "
  WG List: <mailto:ccamp@ietf.org>

  ID-draft editor:
    Haomian Zheng (zhenghaomian@huawei.com);
    Zheyu Fan (fanzheyu2@huawei.com);
    Anurag Sharma (ansha@google.com);
    Xufeng Liu (Xufeng_Liu@jabil.com)
  ";

description
  "This module defines a protocol independent Layer 1/ODU
  topology data model.";

revision 2017-04-25 {
  description
    "Revision 0.3";
  reference
    "draft-zhang-ccamp-l1-topo-yang-07.txt";
}

/*
typedef
*/
```



```
typedef adaptation-type {
  type enumeration {
    enum CBR {
      description "Constant Bit Rate.";
    }
    enum ATMvp {
      description "ATM VP.";
    }
    enum GFP {
      description "Generic Framing Procedure.";
    }
    enum NULL {
      description "NULL";
    }
    enum PRBS {
      description "Pseudo Random Binary Sequence";
    }
    enum RSn {
      description "SDH/SONET section";
    }
    enum ODUj-21 {
      description "ODU payload type 21";
    }
    enum ETHERNET_PP-OS {
      description "ETHERNET_PP-OS, for ODU 2 only";
    }
    enum CBRx {
      description "CBRx(0.. 1.25G), for ODU0 only";
    }
    enum ODU {
      description "Optical Data Unit";
    }
  }

  description
    "Defines a type representing the adaptation type
    on the termination point.";
}

/*
Groupings
*/

grouping otn-topology-type {
  container otn-topology {
    presence "indicates a topology type of Optical
      Transport Network (OTN)-electrical layer.";
  }
}
```

```
    description "otn topology type";
  }
  description "otn-topology-type";
}

grouping otn-topology-attributes {
  leaf name {
    type string;
    description "the topology name";
  }
  description "name attribute for otn topology";
}

grouping otn-node-attributes {
  description "otn-node-attributes";
  leaf name {
    type string;
    description "a name for this node.";
  }
}

grouping otn-link-attributes {
  description "otn link attributes";

  list available-odu-info{
    key "priority";
    max-elements "8";

    description
      "List of ODU type and number on this link";
    leaf priority {
      type uint8 {
        range "0..7";
      }
      description "priority";
    }
  }

  list odulist {
    key "odu-type";

    description
      "the list of available ODUs per priority level";

    leaf odu-type {
      type identityref{
        base tran-types:tributary-protocol-type;
      }
      description "the type of ODU";
    }
  }
}
```

```
    }

    leaf number {
      type uint16;
      description "the number of odu type supported";
    }
  }

  leaf distance {
    type uint32;
    description "distance in the unit of kilometers";
  }
}

grouping otn-tp-attributes {
  description "otn-tp-attributes";

  leaf client-facing {
    type empty;
    description
      "if present, it means this tp is a client-facing tp.
      adding/dropping client signal flow.";
  }

  leaf tpn {
    type uint16 {
      range "0..4095";
    }
    description
      "Tributary Port Number. Applicable in case of mux services.";
    reference
      "RFC7139: GMPLS Signaling Extensions for Control of Evolving
      G.709 Optical Transport Networks.";
  }

  leaf tsg {
    type identityref {
      base tran-types:tributary-slot-granularity;
    }
    description "Tributary slot granularity.";
    reference
      "G.709/Y.1331, February 2012: Interfaces for the Optical
      Transport Network (OTN)";
  }

  leaf protocol-type {
    type identityref {
```

```
    base tran-types:tributary-protocol-type;
  }
  description "Protocol type for the Termination Point.";
}

leaf adaptation-type {
  type adaptation-type;
  description
    "This attribute indicates the type of the supported
    adaptation function at the termination point.";
  reference
    "G.874.1, January 2002: Optical transport network (OTN):
    Protocol-neutral management information model for the
    network element view.";
}

leaf sink-adapt-active {
  type boolean;
  description
    "This attribute allows for activation or deactivation of
    the sink adaptation function. The value of TRUE means active.";

  reference
    "G.874.1, January 2002: Optical transport network (OTN):
    Protocol-neutral management information model for the
    network element view ";
}

leaf source-adapt-active {
  type boolean;
  description
    "This attribute allows for activation or deactivation of
    the sink adaptation function. The value of TRUE
    means active.";
  reference
    "G.874.1, January 2002: Optical transport network (OTN):
    Protocol-neutral management information model for
    the network element view ";
}

container tributary-slots {
  description
    "A list of tributary slots used by the ODU
    Termination Point.";
  leaf-list values {
    type uint8;
    description
      "Tributary slot value.";
  }
}
```

```
        reference
        "G.709/Y.1331, February 2012: Interfaces for the
        Optical Transport Network (OTN)";
    }
}

list supported-payload-types{
    key "index";

    description "supported payload types of a TP";

    leaf index {
        type uint16;
        description "payload type index";
    }

    leaf payload-type {
        type string;
        description "the payload type supported by this client
        tp";
        reference
        "http://www.iana.org/assignments/gmpls-sig-parameters
        /gmpls-sig-parameters.xhtml
        not: the payload type is defined as the generalized PIDs
        in GMPLS.";
    }
}

/*
* Data nodes
*/
augment "/nd:networks/nd:network/nd:network-types/tet:te-topology" {
    uses otn-topology-type;
    description "augment network types to include otn newtork";
}

augment "/nd:networks/nd:network" {
    when "nd:network-types/tet:te-topology/otn-topology" {
        description "Augment only for otn network";
    }
    uses otn-topology-attributes;
    description "Augment network configuration";
}

augment "/nd:networks/nd:network/nd:node" {
    when "../nd:network-types/tet:te-topology/otn-topology" {
```

```
    description "Augment only for otn network";
  }
  description "Augment node configuration";
  uses otn-node-attributes;
}

augment "/nd:networks/nd:network/lnk:link/tet:te/tet:config" {
  when "../../../nd:network-types/tet:te-topology/otn-topology" {
    description "Augment only for otn network.";
  }
  description "Augment link configuration";

  uses otn-link-attributes;
}

augment "/nd:networks/nd:network/lnk:link/tet:te/tet:state" {
  when "../../../nd:network-types/tet:te-topology/otn-topology" {
    description "Augment only for otn network.";
  }
  description "Augment link state";

  uses otn-link-attributes;
}

augment "/nd:networks/nd:network/nd:node/"
+ "lnk:termination-point/tet:te/tet:config" {
  when "../../../nd:network-types/tet:te-topology/otn-topology" {
    description "Augment only for otn network";
  }
  description "OTN TP attributes config in a ODU topology.";
  uses otn-tp-attributes;
}

augment "/nd:networks/nd:network/nd:node/"
+ "lnk:termination-point/tet:te/tet:state" {
  when "../../../nd:network-types/tet:te-topology/otn-topology" {
    description "Augment only for otn network";
  }
  description "OTN TP attributes state in a ODU topology.";
  uses otn-tp-attributes;
}
}

<CODE ENDS>
```

#### 4. IANA Considerations

TBD.

#### 5. Manageability Considerations

TBD.

#### 6. Security Considerations

The data following the model defined in this draft is exchanged via, for example, the interface between an orchestrator and a transport network controller. The security concerns mentioned in [I-D.ietf-teas-yang-te-topo] for using ietf-te-topology.yang model also applies to this draft.

The YANG module defined in this document can be accessed via the RESTCONF protocol defined in [RFC8040], or maybe via the NETCONF protocol [RFC6241].

There are a number of data nodes defined in the YANG module which are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., POST) to these data nodes without proper protection can have a negative effect on network operations.

Editors note: to list specific subtrees and data nodes and their sensitivity/vulnerability.

#### 7. Acknowledgements

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A YANG Data Model for Optical Transport Network Topology  
draft-ietf-ccamp-otn-topo-yang-14

## Abstract

This document describes a YANG data model to describe the topologies of an Optical Transport Network (OTN). It is independent of control plane protocols and captures topological and resource related information pertaining to OTN. This model enables clients, which interact with a transport domain controller, for OTN topology related operations such as obtaining the relevant topology resource information.

## Requirements Language

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

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## 1. Introduction

A transport network is a server-layer network designed to provide connectivity services for a client-layer network to carry the client traffic transparently across the server-layer network resources. A transport network can be constructed of equipments utilizing any of a number of different transport technologies such as the Optical Transport Networks (OTN) or packet transport such as provided by the MPLS-Transport Profile (MPLS-TP).

This document defines a data model of an OTN network topology, using YANG [RFC7950]. The model can be used by an application exposing to a transport controller. Furthermore, it can be used by an application for the following purposes (but not limited to):

- \* To obtain a whole view of the network topology information of its interest;
- \* To receive notifications with regard to the information change of the OTN topology;
- \* To enforce the establishment and update of a network topology with the characteristic specified in the data model;

The YANG model defined in this document is independent of control plane protocols and captures topology related information pertaining to an Optical Transport Networks (OTN) electrical layer, as the scope specified by [RFC7062]. Furthermore, it is not a stand-alone model, but augmenting from the TE topology YANG model defined in [RFC8795], and importing from the generic Layer 1 types defined in [I-D.ietf-ccamp-layer1-types]. Following TE topology YANG model, the YANG model defined in this document is interface independent. The model is included in [I-D.ietf-teas-actn-yang], which indicates the typical usage of IETF YANG models in ACTN architecture specified by [RFC8453]. More specifically, the usage of this model between controllers is described in [I-D.ietf-ccamp-transport-nbi-app-statement].

## 2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this document is defined in [RFC8340]. They are provided below for reference.

- \* Brackets "[" and "]" enclose list keys.
- \* Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- \* Symbols after data node names: "?" means an optional node, "!" means a presence container, and "\*" denotes a list and leaf-list.
- \* Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- \* Ellipsis ("...") stands for contents of subtrees that are not shown.

- \* Some of the key terms used in this document are listed as follow.
- \* TS: Tributary Slot.
- \* TSG: Tributary Slot Granularity.
- \* TPN: Tributary Port Number.

### 3. YANG Data Model for OTN Topology

#### 3.1. OTN Topology Data Model Overview

This document aims to describe the data model for OTN topology. As a classic Traffic-engineering (TE) technology, OTN provide TDM switching in transport network [ITU-Tg709]. Therefore the YANG module presented in this document augments from a more generic Traffic Engineered (TE) network topology data model, i.e., the ietf-te-topology, as specified in [RFC8795]. In section 6 of [RFC8795], the guideline for augmenting TE topology model was provided, and in this draft we augment the TE topology model to describe the topology in OTN network. Common types, identities and groupings defined in [I-D.ietf-ccamp-layer1-types] are reused in this document. [RFC8345] describes a network topology model and provide the fundamental model for [RFC8795]. However, this work is not directly augmenting [RFC8345]. Figure 1 shows the augmentation relationship.

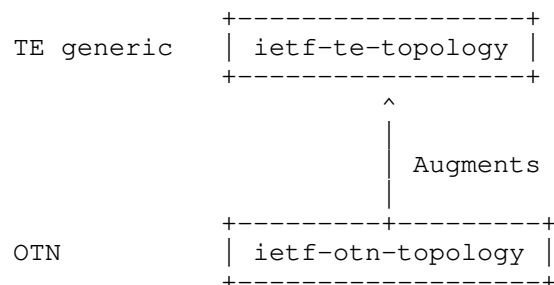


Figure 1 - Relationship between OTN and TE topology models

The entities and TE attributes, such as node, termination points and links, are still applicable for describing an OTN topology and the model presented in this document only specifies with technology-specific attributes/information. The OTN-specific attributes in [RFC7139], including the TPN, TS and TSG, can be used to represent the bandwidth and label information. These attributes have been specified in [I-D.ietf-ccamp-layer1-types], and used in this document for augmentation of the generic TE topology model.

The YANG module `ietf-otn-topology` defined in this document conforms to the Network Management Datastore Architecture (NMDA) defined in [RFC8342].

### 3.2. Attributes Augmentation

There are a few characteristics augmenting to the generic TE topology.

Following the guidelines in [RFC8795], a `otn-topology network-type` is specified as the indicator of OTN in the topology as follow.

```
augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
  +---rw otn-topology!
```

Two OTN technology-specific parameters are specified to augment the generic TE link attributes.

```
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes:
    +---rw tsg?          identityref
    +---rw distance?     uint32
```

In OTN the resources is measured by the tributary slots (TS), as specified in [RFC7139]. The tributary slot granularity (TSG) attribute defines the granularity, such as 1.25G, 2.5G and 5G, used by the TSs of a given OTN link. The distance attribute describes the geographical distance between a pair of OTN link termination points. This is usually measured by the length of the fibre.

The OTN topology model allows reporting also the access links which are capable of supporting the transparent client signals, defined in [I-D.ietf-ccamp-layer1-types]. These links can also be multi-function access links that can support one or more transparent client signals as well as OTN.

A `client-svc` container is specified to augment the generic TE link termination point to describe if the point is capable of carrying client signal and what kind of signal can be carried as follow.

```

augment /nw:networks/nw:network/nw:node/nt:termination-point
  /tet:te:
    +--rw client-svc!
      +--rw client-facing?          boolean
      +--rw supported-client-signal* identityref

```

The client-facing is an indicator on whether the point is needed to carry client signal. A list of support-client-signal is used to provide the capabilities of client signal specified in [I-D.ietf-ccamp-layer1-types].

### 3.3. Bandwidth Augmentation

Following the guidelines in [RFC8795], the model augments all the occurrences of the te-bandwidth container with the OTN technology specific attributes using the otn-link-bandwidth and otn-path-bandwidth groupings defined in [I-D.ietf-ccamp-layer1-types].

### 3.4. Label Augmentation

The model augments all the occurrences of the label-restriction list with OTN technology specific attributes using the otn-label-range-info grouping defined in [I-D.ietf-ccamp-layer1-types].

Moreover, following the guidelines in [RFC8795], the model augments all the occurrences of the te-label container with the OTN technology specific attributes using the otn-label-start-end, otn-label-hop and otn-label-step groupings defined in [I-D.ietf-ccamp-layer1-types].

### 3.5. YANG Tree for OTN topology

```

module: ietf-otn-topology

augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
  +--rw otn-topology!
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes:
    +--rw tsg?          identityref
    +--rw distance?    uint32
augment /nw:networks/nw:network/nw:node/nt:termination-point
  /tet:te:
    +--rw client-svc!
      +--rw client-facing?          boolean
      +--rw supported-client-signal* identityref
augment /nw:networks/nw:network/nw:node/nt:termination-point/tet:te
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:

```



```

+---:(otn)
  +---rw otn
    +---rw odu-type?                                identityref
    +---rw (oduflex-type)?
      +---:(generic)
        | +---rw nominal-bit-rate                    uint64
      +---:(cbr)
        | +---rw client-type                          identityref
      +---:(gfp-n-k)
        | +---rw gfp-n                                uint8
        | +---rw gfp-k?                               gfp-k
      +---:(flexe-client)
        | +---rw flexe-client                        flexe-client-rate
      +---:(flexe-aware)
        | +---rw flexe-aware-n                        uint16
      +---:(packet)
        +---rw opuflex-payload-rate                  uint64
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:path-constraints/tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
  +---rw odu-type    identityref
  +---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
  +---rw odu-type    identityref
  +---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:path-constraints/tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
  +---ro odu-type    identityref
  +---ro number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
  +---ro odu-type    identityref
  +---ro number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te

```

```

        /tet:tunnel-termination-point/tet:client-layer-adaptation
        /tet:switching-capability/tet:te-bandwidth
        /tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:path-constraints
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw otn
    +---rw odu-type?      identityref
    +---rw (oduflex-type)?
      +---:(generic)
        | +---rw nominal-bit-rate      uint64
      +---:(cbr)
        | +---rw client-type            identityref
      +---:(gfp-n-k)
        | +---rw gfp-n                  uint8
        | +---rw gfp-k?                  gfp-k
      +---:(flexe-client)
        | +---rw flexe-client            flexe-client-rate
      +---:(flexe-aware)
        | +---rw flexe-aware-n            uint16
      +---:(packet)
        +---rw opuflex-payload-rate      uint64
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:max-link-bandwidth
  /tet:te-bandwidth/tet:technology:

```

```

+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:max-resv-link-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:te-link-attributes/tet:unreserved-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---rw odulist* [odu-type]
    +---rw odu-type      identityref
    +---rw number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry
  /tet:interface-switching-capability/tet:max-lsp-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro otn
    +---ro odu-type?      identityref
    +---ro (oduflex-type)?
      +---:(generic)
        | +---ro nominal-bit-rate      uint64
      +---:(cbr)
        | +---ro client-type            identityref
      +---:(gfp-n-k)
        | +---ro gfp-n                  uint8
        | +---ro gfp-k?                 gfp-k
      +---:(flexe-client)
        | +---ro flexe-client            flexe-client-rate
      +---:(flexe-aware)
        | +---ro flexe-aware-n           uint16
      +---:(packet)
        +---ro opuflex-payload-rate      uint64
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry/tet:max-link-bandwidth
  /tet:te-bandwidth/tet:technology:
+---:(otn)
  +---ro odulist* [odu-type]
    +---ro odu-type      identityref
    +---ro number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
  /tet:information-source-entry/tet:max-resv-link-bandwidth

```

```

        /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---ro odulist* [odu-type]
        +---ro odu-type      identityref
        +---ro number?       uint16
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:unreserved-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---ro odulist* [odu-type]
        +---ro odu-type      identityref
        +---ro number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes
    /tet:interface-switching-capability/tet:max-lsp-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw otn
        +---rw odu-type?          identityref
        +---rw (oduflex-type)?
            +---:(generic)
                | +---rw nominal-bit-rate      uint64
            +---:(cbr)
                | +---rw client-type            identityref
            +---:(gfp-n-k)
                | +---rw gfp-n                  uint8
                | +---rw gfp-k?                  gfp-k
            +---:(flexe-client)
                | +---rw flexe-client            flexe-client-rate
            +---:(flexe-aware)
                | +---rw flexe-aware-n            uint16
            +---:(packet)
                +---rw opuflex-payload-rate      uint64
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:max-link-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw odulist* [odu-type]
        +---rw odu-type      identityref
        +---rw number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:max-resv-link-bandwidth
    /tet:te-bandwidth/tet:technology:
+---:(otn)
    +---rw odulist* [odu-type]
        +---rw odu-type      identityref
        +---rw number?       uint16
augment /nw:networks/tet:te/tet:templates/tet:link-template

```

```

        /tet:te-link-attributes/tet:unreserved-bandwidth
        /tet:te-bandwidth/tet:technology:
+---:(otn)
+---rw odulist* [odu-type]
+---rw odu-type    identityref
+---rw number?     uint16
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:from/tet:label-restrictions
        /tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction:
+---rw range-type?    otn-label-range-type
+---rw tsg?           identityref
+---rw odu-type-list* identityref
+---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:label-restrictions/tet:label-restriction:
+---ro range-type?    otn-label-range-type
+---ro tsg?           identityref
+---ro odu-type-list* identityref
+---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:from/tet:label-restrictions
        /tet:label-restriction:
+---ro range-type?    otn-label-range-type
+---ro tsg?           identityref
+---ro odu-type-list* identityref
+---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction:

```

```

    +---ro range-type?      otn-label-range-type
    +---ro tsg?             identityref
    +---ro odu-type-list*   identityref
    +---ro priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction:
    +---ro range-type?      otn-label-range-type
    +---ro tsg?             identityref
    +---ro odu-type-list*   identityref
    +---ro priority?        uint8
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw range-type?      otn-label-range-type
    +---rw tsg?             identityref
    +---rw odu-type-list*   identityref
    +---rw priority?        uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-start/tet:te-label/tet:technology:
    +---:(otn)
        +---rw (range-type)?

```

```

      +---:(trib-port)
      |   +---rw otn-tpn?    otn-tpn
      +---:(trib-slot)
          +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-end/tet:te-label/tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-step/tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
        +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:primary-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:backup-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)

```

```

    +--rw otn-tpn?    otn-tpn
    +--rw tsg?        identityref
    +--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
    +--rw otn-tpn?    otn-tpn
    +--rw tsg?        identityref
    +--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+--:(otn)
    +--ro otn-tpn?    otn-tpn
    +--ro tsg?        identityref
    +--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    |   +--:(trib-port)
    |   |   +--rw otn-tpn?    otn-tpn
    |   +--:(trib-slot)
    |   |   +--rw otn-ts?     otn-ts
    |   +--rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    |   +--:(trib-port)
    |   |   +--rw otn-tpn?    otn-tpn
    |   +--:(trib-slot)
    |   |   +--rw otn-ts?     otn-ts
    |   +--rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions

```



```

        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
+---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
+---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
+---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:to/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
+---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:te-node-attributes/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:underlay/tet:primary-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string

```

```

augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--rw otn-tpn?    otn-tpn
+--rw tsg?        identityref
+--rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:path-properties
  /tet:path-route-objects/tet:path-route-object/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+--:(otn)
+--ro otn-tpn?    otn-tpn
+--ro tsg?        identityref
+--ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-start/tet:te-label/tet:technology:
+--:(otn)
+--ro (range-type)?
+--:(trib-port)
|   +--ro otn-tpn?    otn-tpn

```

```

      +---:(trib-slot)
        +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-end/tet:te-label/tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:label-restrictions/tet:label-restriction
  /tet:label-step/tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---ro otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:underlay/tet:primary-path/tet:path-element/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref
  +---ro ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:underlay/tet:backup-path/tet:path-element/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref
  +---ro ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:optimizations/tet:algorithm/tet:metric
  /tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?      otn-tpn
  +---ro tsg?          identityref

```

```

    +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---ro otn-tpn?    otn-tpn
    +---ro ts-g?        identityref
    +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(otn)
    +---ro otn-tpn?    otn-tpn
    +---ro ts-g?        identityref
    +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(otn)
    +---ro (range-type)?
    +---:(trib-port)
    |   +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---ro otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(otn)
    +---ro (range-type)?
    +---:(trib-port)
    |   +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---ro otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)

```

```

    +---ro (range-type)?
      +---:(trib-port)
        | +---ro otn-tpn?    otn-tpn
      +---:(trib-slot)
        +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---ro (range-type)?
    +---:(trib-port)
      | +---ro otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:primary-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(otn)
  +---ro otn-tpn?    otn-tpn
  +---ro tsg?        identityref
  +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices

```

```

        /tet:connectivity-matrix/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:optimizations/tet:algorithm
        /tet:metric/tet:optimization-metric
        /tet:explicit-route-exclude-objects
        /tet:route-object-exclude-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:optimizations/tet:algorithm
        /tet:metric/tet:optimization-metric
        /tet:explicit-route-include-objects
        /tet:route-object-include-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:information-source-entry/tet:connectivity-matrices
        /tet:connectivity-matrix/tet:path-properties
        /tet:path-route-objects/tet:path-route-object/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro ts-g?      identityref
+---ro ts-list?   string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:tunnel-termination-point
        /tet:local-link-connectivities/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)

```

```

      +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+---:(otn)
  +---rw (range-type)?
  +---:(trib-port)
  |   +---rw otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---rw (range-type)?
  +---:(trib-port)
  |   +---rw otn-tpn?      otn-tpn
  +---:(trib-slot)
  +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?      otn-tpn
  +---rw tsg?          identityref
  +---rw ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:backup-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?      otn-tpn
  +---rw tsg?          identityref
  +---rw ts-list?      string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)

```

```

    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---rw otn-tpn?    otn-tpn
    +---rw tsg?        identityref
    +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
    +---ro otn-tpn?    otn-tpn
    +---ro tsg?        identityref
    +---ro ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(otn)
    +---rw (range-type)?
    +---:(trib-port)
    |   +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
    |   +---rw otn-ts?     otn-ts
augment /nw:networks/nw:network/nw:node/tet:te

```



```

        /tet:tunnel-termination-point
        /tet:local-link-connectivities
        /tet:local-link-connectivity/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---rw (range-type)?
    +---:(trib-port)
      | +---rw otn-tpn?    otn-tpn
    +---:(trib-slot)
      +---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn
  +---rw tsg?        identityref
  +---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects

```

```

        /tet:route-object-include-object/tet:type/tet:label
        /tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nw:node/tet:te
        /tet:tunnel-termination-point
        /tet:local-link-connectivities
        /tet:local-link-connectivity/tet:path-properties
        /tet:path-route-objects/tet:path-route-object/tet:type
        /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(otn)
+---ro otn-tpn?    otn-tpn
+---ro tsg?        identityref
+---ro ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:underlay/tet:primary-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(otn)
+---rw otn-tpn?    otn-tpn
+---rw tsg?        identityref
+---rw ts-list?    string
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?
+---:(trib-port)
|   +---rw otn-tpn?    otn-tpn
+---:(trib-slot)
+---rw otn-ts?      otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(otn)
+---rw (range-type)?

```

```

      +---:(trib-port)
      |   +---rw otn-tpn?    otn-tpn
      +---:(trib-slot)
          +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
      /tet:te-link-attributes/tet:label-restrictions
      /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---rw (range-type)?
  +---:(trib-port)
  |   +---rw otn-tpn?    otn-tpn
  +---:(trib-slot)
      +---rw otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
      /tet:information-source-entry/tet:label-restrictions
      /tet:label-restriction/tet:label-start/tet:te-label
      /tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?    otn-tpn
  +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
      /tet:information-source-entry/tet:label-restrictions
      /tet:label-restriction/tet:label-end/tet:te-label
      /tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?    otn-tpn
  +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/nw:network/nt:link/tet:te
      /tet:information-source-entry/tet:label-restrictions
      /tet:label-restriction/tet:label-step/tet:technology:
+---:(otn)
  +---ro (range-type)?
  +---:(trib-port)
  |   +---ro otn-tpn?    otn-tpn
  +---:(trib-slot)
      +---ro otn-ts?    otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
      /tet:te-link-attributes/tet:underlay/tet:primary-path
      /tet:path-element/tet:type/tet:label/tet:label-hop
      /tet:te-label/tet:technology:
+---:(otn)
  +---rw otn-tpn?    otn-tpn

```

```

    +--rw tsg?          identityref
    +--rw ts-list?      string
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:underlay/tet:backup-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+--:(otn)
    +--rw otn-tpn?     otn-tpn
    +--rw tsg?         identityref
    +--rw ts-list?     string
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?     otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?      otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?     otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?      otn-ts
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+--:(otn)
    +--rw (range-type)?
    +--:(trib-port)
    |   +--rw otn-tpn?     otn-tpn
    +--:(trib-slot)
    |   +--rw otn-ts?      otn-ts

```

#### 4. The YANG Code

```
<CODE BEGINS> file "ietf-otn-topology@2021-07-08.yang"
module ietf-otn-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-otn-topology";
  prefix "otnt";

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

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

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

  import ietf-layer1-types {
    prefix "l1-types";
    reference
      "I-D.ietf-ccamp-layer1-types: A YANG Data Model
      for Layer 1 Types";
  }

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

    Editor: Haomian Zheng
           <mailto:zhenghaomian@huawei.com>

    Editor: Italo Busi
           <mailto:italo.busi@huawei.com>

    Editor: Xufeng Liu
           <mailto:xufeng.liu.ietf@gmail.com>

    Editor: Sergio Belotti
           <mailto:sergio.belotti@nokia.com>
```

Editor: Oscar Gonzalez de Dios  
 <mailto:oscar.gonzalezdedios@telefonica.com>;

#### description

"This module defines a protocol independent Layer 1/ODU topology data model. The model fully conforms to the Network Management Datastore Architecture (NMDA).

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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 (<https://trustee.ietf.org/license-info>). This version of this YANG module is part of RFC XXXX; see the RFC itself for full legal notices.";

#### revision 2021-07-08 {

##### description

"Initial Revision";

##### reference

"RFC XXXX: A YANG Data Model for Optical Transport Network Topology";

// RFC Ed.: replace XXXX with actual RFC number, update date  
 // information and remove this note

}

/\*

\* Data nodes

\*/

augment "/nw:networks/nw:network/nw:network-types/"

+ "tet:te-topology" {

container otn-topology {

presence "indicates a topology type of Optical Transport Network (OTN)-electrical layer.";

description "otn topology type";

}

description "augment network types to include otn network";

}

augment "/nw:networks/nw:network/nt:link/tet:te/"

+ "tet:te-link-attributes" {

when "../../nw:network-types/tet:te-topology/"

+ "otnt:otn-topology" {

```
    description "Augment only for otn network.";
  }
  description "Augment link configuration";

  leaf tsg {
    type identityref {
      base ll-types:tributary-slot-granularity;
    }
    description "Tributary slot granularity.";
    reference
      "G.709/Y.1331, February 2016: Interfaces for the
      Optical Transport Network (OTN)";
  }
  leaf distance {
    type uint32;
    description "distance in the unit of kilometers";
  }
}

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
  + "tet:te" {
  when "../.../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description "Augment only for otn network";
  }
  description "OTN TP attributes config in ODU topology.";

  container client-svc {
    presence "client-facing LTP.";
    description
      "OTN LTP Service attributes.";

    leaf client-facing {
      type boolean;
      default 'false';
      description
        "Indicates whether this LTP is a client-facing LTP.";
    }
    leaf-list supported-client-signal {
      type identityref {
        base ll-types:client-signal;
      }
      description
        "List of client signal types supported by the LTP.";
    }
  }
}
```

```

/*
 * Augment TE bandwidth
 */

augment "/nw:networks/nw:network/nw:node/nt:termination-point/"
    + "tet:te/"
    + "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment maximum LSP TE bandwidth for the link termination
        point (LTP).";
case otn {
uses ll-types:otn-path-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE bandwidth path constraints of the TE node
        connectivity matrices.";
case otn {
uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
        OTN topology type.";

```



```

    }
    description
      "Augment TE bandwidth path constraints of the
       connectivity matrix entry.";
    case otn {
      uses ll-types:otn-link-bandwidth;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE bandwidth path constraints of the TE node
     connectivity matrices information source.";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:path-constraints/tet:te-bandwidth/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE bandwidth path constraints of the
     connectivity matrix entry information source";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:client-layer-adaptation/tet:switching-capability/"
  + "tet:te-bandwidth/tet:technology" {

```

```

when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment client TE bandwidth of the tunnel termination point
  (TTP)";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/tet:path-constraints/"
+ "tet:te-bandwidth/tet:technology" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE bandwidth path constraints for the TTP
  Local Link Connectivities.";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/tet:path-constraints/"
+ "tet:te-bandwidth/tet:technology" {
when "../../../../../../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE bandwidth path constraints for the TTP
  Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-link-bandwidth;
}
}

```

```

    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:interface-switching-capability/tet:max-lsp-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment maximum LSP TE bandwidth for the TE link.";
    case otn {
      uses ll-types:otn-path-bandwidth;
    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:max-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment maximum TE bandwidth for the TE link";
    case otn {
      uses ll-types:otn-link-bandwidth;
    }
  }

  augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:max-resv-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../../../nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description

```

```
    "Augment maximum reservable TE bandwidth for the TE link";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:unreserved-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment unreserved TE bandwidth for the TE Link";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:interface-switching-capability/"
  + "tet:max-lsp-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment maximum LSP TE bandwidth for the TE link
    information source";
  case otn {
    uses ll-types:otn-path-bandwidth;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:max-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
```

```
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment maximum TE bandwidth for the TE link
        information source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:max-resv-link-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../.../.../nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment maximum reservable TE bandwidth for the TE link
        information-source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:unreserved-bandwidth/"
    + "tet:te-bandwidth/tet:technology" {
    when "../.../.../nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment unreserved TE bandwidth of the TE link
        information source";
    case otn {
        uses ll-types:otn-link-bandwidth;
    }
}
```

```
augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:interface-switching-capability/"
  + "tet:max-lsp-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum LSP TE bandwidth of the TE link
    template";
  case otn {
    uses ll-types:otn-path-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:max-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum TE bandwidth the TE link template";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:max-resv-link-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment maximum reservable TE bandwidth for the TE link
    template.";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:unreserved-bandwidth/"
  + "tet:te-bandwidth/tet:technology" {
  description
    "Augment unreserved TE bandwidth the TE link template";
  case otn {
    uses ll-types:otn-link-bandwidth;
  }
}

/*
```

```
* Augment TE label range information
*/

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the TE node
    connectivity matrices.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the source LTP
    of the connectivity matrix entry.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range information for the destination LTP
    of the connectivity matrix entry.";
uses ll-types:otn-label-range-info;
```

```
}  
augment "/nw:networks/nw:network/nw:node/tet:te/"  
    + "tet:information-source-entry/"  
    + "tet:connectivity-matrices/tet:label-restrictions/"  
    + "tet:label-restriction" {  
when "../.../../.../../nw:network-types/tet:te-topology/"  
    + "otnt:otn-topology" {  
description  
    "Augmentation parameters apply only for networks with  
        OTN topology type.";  
}  
description  
    "Augment TE label range information for the TE node  
        connectivity matrices information source.";  
uses ll-types:otn-label-range-info;  
}  
  
augment "/nw:networks/nw:network/nw:node/tet:te/"  
    + "tet:information-source-entry/tet:connectivity-matrices/"  
    + "tet:connectivity-matrix/"  
    + "tet:from/tet:label-restrictions/tet:label-restriction" {  
when "../.../../.../../nw:network-types/tet:te-topology/"  
    + "otnt:otn-topology" {  
description  
    "Augmentation parameters apply only for networks with  
        OTN topology type.";  
}  
description  
    "Augment TE label range information for the source LTP  
        of the connectivity matrix entry information source.";  
uses ll-types:otn-label-range-info;  
}  
  
augment "/nw:networks/nw:network/nw:node/tet:te/"  
    + "tet:information-source-entry/tet:connectivity-matrices/"  
    + "tet:connectivity-matrix/"  
    + "tet:to/tet:label-restrictions/tet:label-restriction" {  
when "../.../../.../../nw:network-types/tet:te-topology/"  
    + "otnt:otn-topology" {  
description  
    "Augmentation parameters apply only for networks with  
        OTN topology type.";  
}  
description  
    "Augment TE label range information for the destination LTP  
        of the connectivity matrix entry information source.";  
uses ll-types:otn-label-range-info;
```



```

}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TTP
Local Link Connectivities.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TTP
Local Link Connectivity entry.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
"Augmentation parameters apply only for networks with
OTN topology type.";
}
description
"Augment TE label range information for the TE link.";
uses ll-types:otn-label-range-info;
}

```

```

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:label-restrictions/tet:label-restriction" {
when "../../../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range information for the TE link
  information source.";
uses ll-types:otn-label-range-info;
}

augment "/nw:networks/tet:te/tet:templates/"
  + "tet:link-template/tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction" {
  description
    "Augment TE label range information for the TE link template.";
  uses ll-types:otn-label-range-info;
}

/*
 * Augment TE label
 */

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../../../nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the TE node
  connectivity matrices";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"

```

```

+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range end for the TE node
      connectivity matrices";
case otn {
    uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-step/"
+ "tet:technology" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
description
    "Augment TE label range step for the TE node
      connectivity matrices";
case otn {
    uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../.../../.../../.../../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
      OTN topology type.";
}
}
```

```

    description
      "Augment TE label hop for the underlay primary path of the
       TE node connectivity matrices";
    case otn {
      uses ll-types:otn-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:underlay/tet:backup-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path of the
     TE node connectivity matrices";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
     by the path computation of the TE node connectivity
     matrices";
  case otn {

```

```

    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the TE node connectivity
  matrices";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the TE node connectivity matrices";
case otn {
  uses ll-types:otn-label-hop;
}
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the source LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range end for the source LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:from/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {

```

```

when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the source LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the destination LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology" {
when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
}

```

```

    }
    description
      "Augment TE label range end for the destination LTP
      of the connectivity matrix entry.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the connectivity matrix entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

```



```

    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/"
    + "tet:type/tet:label/tet:label-hop/"
    + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path
     of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"
  + "tet:algorithm/tet:metric/tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
     by the path computation of the connectivity matrix entry.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"

```

```

    + "tet:connectivity-matrix/tet:optimizations/"
    + "tet:algorithm/tet:metric/tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the connectivity matrix entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the connectivity matrix entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"

```

```

    + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
         OTN topology type.";
    }
  description
    "Augment TE label range start for the TE node connectivity
     matrices information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label range end for the TE node connectivity
     matrices information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-step/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
       OTN topology type.";
  }
  description
    "Augment TE label range step for the TE node connectivity
     matrices information source.";

```

```

    case otn {
      uses ll-types:otn-label-step;
    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
      + "nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment TE label hop for the underlay primary path
      of the TE node connectivity matrices of the information
      source entry.";
    case otn {
      uses ll-types:otn-label-hop;
    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
      + "nw:network-types/tet:te-topology/"
      + "otnt:otn-topology" {
      description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
      "Augment TE label hop for the underlay backup path
      of the TE node connectivity matrices of the information
      source entry.";
    case otn {
      uses ll-types:otn-label-hop;
    }
  }

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

```

```

    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TE node connectivity matrices
    information source.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TE node connectivity matrices
    information source.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {

```

```

when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
  }
  description
    "Augment TE label hop for the computed path route objects
    of the TE node connectivity matrices information source.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
    }
    description
      "Augment TE label range start for the source LTP
      of the connectivity matrix entry information source.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
    }
  }
}

```

```

    description
      "Augment TE label range end for the source LTP
      of the connectivity matrix entry information source.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/"
  + "tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the source LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range start for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range end for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry information source.";
case otn {
  uses ll-types:otn-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {

```



```

        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the connectivity matrix entry information source.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the connectivity matrix entry information source.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description

```

```

    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the connectivity matrix entry
    information source.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the connectivity matrix entry
  information source.";
  case otn {
    uses ll-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the connectivity matrix entry information source.";

```

```

    case otn {
      uses ll-types:otn-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label range start for the TTP
    Local Link Connectivities.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/"
+ "tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
      OTN topology type.";
  }
  description
    "Augment TE label range end for the TTP
    Local Link Connectivities.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology"{
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label range step for the TTP
        Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-step;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects excluded
        by the path computation of the TTP Local Link
        Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description

```

```

        "Augmentation parameters apply only for networks with
        OTN topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects included
        by the path computation of the TTP Local Link
        Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label hop for the computed path route objects
        of the TTP Local Link Connectivities.";
    case otn {
        uses ll-types:otn-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "otnt:otn-topology" {
        description
            "Augmentation parameters apply only for networks with
            OTN topology type.";
    }
    description
        "Augment TE label range start for the TTP

```

```

        Local Link Connectivity entry.";
    case otn {
        uses ll-types:otn-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE label range end for the TTP
    Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
    description
        "Augmentation parameters apply only for networks with
        OTN topology type.";
}
description
    "Augment TE label range step for the TTP
    Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-step;
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the TTP Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "otnt:otn-topology" {
  description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the TTP Local Link Connectivity entry.";
case otn {
  uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```



```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TTP Local Link
    Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}

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

```

```

    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the TTP Local Link Connectivity entry.";
case otn {
    uses ll-types:otn-label-hop;
}
}
augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label hop for the underlay primary path
    of the TE link.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description

```

```

    "Augment TE label hop for the underlay backup path
      of the TE link.";
  case otn {
    uses l1-types:otn-label-hop;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range start for the TE link.";
  case otn {
    uses l1-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range end for the TE link.";
  case otn {
    uses l1-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:te-link-attributes/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description

```

```

        "Augmentation parameters apply only for networks with
          OTN topology type.";
    }
    description
      "Augment TE label range step for the TE link.";
    case otn {
      uses ll-types:otn-label-step;
    }
  }

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/tet:te-label/tet:technology" {
  when "../..//../..//../..//nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range start for the TE link
      information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
  when "../..//../..//../..//nw:network-types/tet:te-topology/"
    + "otnt:otn-topology" {
    description
      "Augmentation parameters apply only for networks with
        OTN topology type.";
  }
  description
    "Augment TE label range end for the TE link
      information source.";
  case otn {
    uses ll-types:otn-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
  + "tet:information-source-entry/"

```

```

+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../nw:network-types/tet:te-topology/"
+ "otnt:otn-topology" {
description
    "Augmentation parameters apply only for networks with
    OTN topology type.";
}
description
    "Augment TE label range step for the TE link
    information source.";
case otn {
    uses ll-types:otn-label-step;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
description
    "Augment TE label hop for the underlay primary path
    of the TE link template.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
description
    "Augment TE label hop for the underlay backup path
    of the TE link template.";
case otn {
    uses ll-types:otn-label-hop;
}
}

augment "/nw:networks/tet:te/tet:templates/"
+ "tet:link-template/tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
description
    "Augment TE label range start for the TE link template.";
case otn {
    uses ll-types:otn-label-start-end;

```

```

    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    description
      "Augment TE label range end for the TE link template.";
    case otn {
      uses ll-types:otn-label-start-end;
    }
  }

  augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/tet:technology" {
    description
      "Augment TE label range step for the TE link template.";
    case otn {
      uses ll-types:otn-label-step;
    }
  }
}
<CODE ENDS>

```

## 5. IANA Considerations

It is proposed to IANA to assign new URIs from the "IETF XML Registry" [RFC3688] as follows:

```

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

```

This document registers a YANG module in the YANG Module Names registry [RFC7950].

```

name:      ietf-otn-topology
namespace: urn:ietf:params:xml:ns:yang:ietf-otn-topology
prefix:    otnt
reference: RFC XXXX

```

## 6. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

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Information Model for Wavelength Switched Optical Networks (WSONs) with  
Impairments Validation  
draft-ietf-ccamp-wson-iv-info-05

Abstract

This document defines an information model to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functionality. This information model extends the information model for impairment-free RWA process in WSON to facilitate computation of paths where optical impairment constraints need to be considered.

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## 1. Introduction

In the context of Wavelength Switched Optical Network (WSON), [RFC6163] describes the basic framework for a GMPLS and PCE-based Routing and Wavelength Assignment (RWA) control plane. The associated information model [RFC7446] defines information/parameters required by an RWA process without optical impairment considerations.

There are cases of WSON where optical impairments play a significant role and are considered as important constraints. The framework document [RFC6566] defines the problem scope and related control plane architectural options for the Impairment Aware RWA (IA-RWA) operation. Options include different combinations of Impairment Validation (IV) and RWA functions in term of different combination of control plane functions (i.e., PCE, Routing, Signaling).

A Control Plane with RWA-IA will not be able to solve the optical impairment problem in a detailed and exhaustive way, however, it may take advantage of some data plane knowledge to make better decisions during its path computing phase. The final outcome will be a path, instantiated through a wavelength in the data plane, that has a "better chance" to work than that path were calculated without IA information. "Better chance" means that path setup may still fail and the GMPLS control plane will follow its usual procedures upon errors and failures. A control plane will not replace a the network design phase that remains a fundamental step for DWDM Optical Networks. As the non-linear impairments which need to be considered in the calculation of an optical path will be vendor-dependent, the parameters considered in this document is not an exhaustive list.

This document provides an information model for the impairment aware case to allow the impairment validation function implemented in the control plane or enabled by control plane available information. This model goes in addition to [RFC7446] and shall support any control plane architectural option described by the framework document (see sections 4.2 and 4.3 of [RFC6566]) where a set of combinations of control plane functions vs. IV function is provided.

## 2. Definitions, Applicability and Properties

This section provides some concepts to help understand the model and to make a clear separation from data plane definitions (ITU-T recommendations). The first sub-section provides definitions while the Applicability sections uses the defined definitions to scope this document.

## 2.1. Definitions

- o Computational Model / Optical Computational Model.  
Defined by ITU standard documents. In this context we look for models able to compute optical impairments for a given lightpath.
- o Information Model.  
Defined by IETF (this document) and provides the set of information required by control plane to apply the Computational Model.
- o Level of Approximation.  
This concept refers to the Computational Model as it may compute optical impairment with a certain level of uncertainty. This level is generally not measured but [RFC6566] Section 4.1.1 provides a rough classification about it.
- o Feasible Path.  
It is the output of the C-SPF with RWA-IV capability. It's an optical path that satisfies optical impairment constraints. The path, instantiated through wavelength(s), may actually work or not work depending of the level of approximation.
- o Existing Service Disruption.  
An effect known to optical network designers is the cross-interaction among spectrally adjacent wavelengths: an existing wavelength may experience increased BER due to the setup of an adjacent wavelength. Solving this problem is a typical optical network design activity. Just as an example, a simple solution is adding optical margins (e.g., additional OSNR), although complex and detailed methods exist.
- o DWDM Line Segments.  
[ITU.G680] provides definition and picture for the "Situation 1" DWDM Line segments: " Situation 1 - The optical path between two consecutive 3R regenerators is composed of DWDM line segments from a single vendor and OADMs and PXC's from another vendor". Document [RFC6566] Figure 1 shows an LSP composed by two DWDM line segments according to [ITU.G680] definition.

## 2.2. Applicability

This document targets at Scenario C defined in [RFC6566] section 4.1.1. as approximate impairment estimation. The Approximate concept refer to the fact that this Information Model covers information mainly provided by [ITU.G680] Computational Model.

Computational models having no or little approximation, referred as IV-Detailed in the [RFC6566], currently does not exist in term of ITU-T recommendation. They generally deal with non-linear optical impairment and are usually vendor specific.

The Information Model defined in this document does not speculate about the mathematical formulas used to fill up information model parameters, hence it does not preclude changing the computational model. At the same time, the authors do not believe this Information Model is exhaustive and if necessary further documents will cover additional models after they become available.

The result of RWA-IV process implementing this Information Model is a path (and a wavelength in the data plane) that has better chance to be feasible than if it was computed without any IV function. The Existing Service Disruption, as per the definition above, would still be a problem left to a network design phase.

### 2.3. Properties

An information model may have several attributes or properties that need to be defined for each optical parameter made available to the control plane. The properties will help to determine how the control plane can deal with a specific impairment parameter, depending on architectural options chosen within the overall impairment framework [RFC6566]. In some case, properties value will help to identify the level of approximation supported by the IV process.

- o Time Dependency

This identifies how an impairment parameter may vary with time. There could be cases where there is no time dependency, while in other cases there may be need of re-evaluation after a certain time. In this category, variations in impairments due to environmental factors such as those discussed in [ITU.GSUP47] are considered. In some cases, an impairment parameter that has time dependency may be considered as a constant for approximation. In this information model, we do neglect this property.

- o Wavelength Dependency

This property identifies if an impairment parameter can be considered as constant over all the wavelength spectrum of interest or not. Also in this case a detailed impairment evaluation might lead to consider the exact value while an approximation IV might take a constant value for all wavelengths. In this information model, we consider both case: dependency / no dependency on a specific wavelength. This property appears directly in the information model definitions and related encoding.



- o Linearity

As impairments are representation of physical effects, there are some that have a linear behaviour while other are non-linear. Linear approximation is in scope of Scenario C of [RFC6566]. During the impairment validation process, this property implies that the optical effect (or quantity) satisfies the superposition principle, thus a final result can be calculated by the sum of each component. The linearity implies the additivity of optical quantities considered during an impairment validation process. The non-linear effects in general do not satisfy this property. The information model presented in this document however, easily allow introduction of non-linear optical effects with a linear approximated contribution to the linear ones.

- o Multi-Channel

There are cases where a channel's impairments take different values depending on the aside wavelengths already in place, this is mostly due to non-linear impairments. The result would be a dependency among different LSPs sharing the same path. This information model do not consider this kind of property.

The following table summarise the above considerations where in the first column reports the list of properties to be considered for each optical parameter, while the second column states if this property is taken into account or not by this information model.

Property	Info Model Awareness
Time Dependency	no
Wavelength Dependency	yes
Linearity	yes
Multi-channel	no

Table 1: Optical Impairment Properties

### 3. ITU-T List of Optical Parameters

As stated by Section 2.2 this Information Model does not intend to be exhaustive and targets an approximate computational model although not precluding future evolutions towards more detailed or different impairments estimation methods.

On the same line, ITU SG15/Q6 provides (through [LS78]) a list of optical parameters with following observations:

- (a) the problem of calculating the non-linear impairments in a multi-vendor environment is not solved. The transfer functions works only for the so called [ITU.G680] "Situation 1".
- (b) The generated list of parameters is not exhaustive however provide a guideline for control plane optical impairment awareness.

In particular, [ITU.G680] contains many parameters that would be required to estimate linear impairments. Some of the Computational Models defined within [ITU.G680] requires parameters defined in other documents like [ITU.G671]. The purpose of the list here below makes this match between the two documents.

[ITU.G697] defines parameters can be monitored in an optical network. This Information Model and associated encoding document will reuse [ITU.G697] parameters identifiers and encoding for the purpose of path computation.

The list of optical parameters starts from [ITU.G680] Section 9 which provides the optical computational models for the following p:

G-1 OSNR. Section 9.1

G-2 Chromatic Dispersion (CD). Section 9.2

G-3 Polarization Mode Dispersion (PMD). Section 9.3

G-4 Polarization Dependent Loss (PDL). Section 9.3

In addition to the above, the following list of parameters has been mentioned by [LS78]:

- L-1 "Channel frequency range", [ITU.G671]. This parameter is part of the application code and encoded through Optical Interface Class as defined in [RFC7446].
- L-2 "Modulation format and rate". This parameter is part of the application code and encoded through Optical Interface Class as defined in [RFC7446].
- L-3 "Channel power". Required by G-1.
- L-4 "Ripple". According to [ITU.G680], this parameter can be taken into account as additional OSNR penalty.
- L-5 "Channel signal-spontaneous noise figure", [ITU.G680]. Required by OSNR calculation (see G-1) above.

- L-6 "Channel chromatic dispersion (for fibre segment or network element)". Already in G-2 above.
- L-7 "Channel local chromatic dispersion (for a fibre segment)". Already in G-2 above (since consider both local and fiber dispersions).
- L-8 "Differential group delay (for a network element)", [ITU.G671]. Required by G-3.
- L-9 "Polarisation mode dispersion (for a fibre segment)", [ITU.G650.2], [ITU.G680]. Defined above as G-3.
- L-10 "Polarization dependent loss (for a network element)", [ITU.G671] and [ITU.G680]. Defined above as G-4.
- L-11 "Reflectance". From [ITU.G671] Section 3.2.2.37 is the ratio of reflected power  $P_r$  to incident power  $P_i$  at a given port of a passive component, for given conditions of spectral composition, polarization and geometrical distribution. Generally expressed in dB. Might be monitored in some critical cases. We neglect this effect as first approximation.
- L-12 "Channel Isolation". From [ITU.G671] Section 3.2.2.2 (Adjacent Channel Isolation) and Section 3.2.2.29 (Non Adjacent Channel Isolation). Document [ITU.GSUP39] provide the formula for calculation as channel cross-talk and measure it in dB. This parameter shall be considered for path computation.
- L-13 "Channel extinction". From [ITU.G671] Section 3.2.2.9 needed for Interferometric Crosstalk. Document [ITU.GSUP39] has the formula for penalty computation. Unit of measurement is dB.
- L-14 "Attenuation coefficient (for a fibre segment)". Document [ITU.G650.1] Section 3.6.2. The unit of measure is dB. This is a typical link parameter (as associated to a fiber).
- L-15 "Non-linear coefficient (for a fibre segment)", [ITU.G650.2]. Required for Non-Linear Optical Impairment Computational Models. Neglected by this document.

The final list of parameters is G-1, G-2, G-3, G-4, L-3, L-4, L-5, L-8, L-12, L-13, L-14.

#### 4. Background from WSON-RWA Information Model

In this section we report terms already defined for the WSON-RWA (impairment free) as in [RFC7446] and [RFC7579]. The purpose is to provide essential information that will be reused or extended for the impairment case.

In particular [RFC7446] Section 4.1 defines the ConnectivityMatrix and states that such matrix does not represent any particular internal blocking behaviour but indicates which input ports and wavelengths could possibly be connected to a particular output port.

```
<ConnectivityMatrix> ::= <MatrixID> <ConnType> <Matrix>
```

According to [RFC7579], this definition is further detailed as:

```
<ConnectivityMatrix> ::=  
    <MatrixID> <ConnType> ((<LinkSet> <LinkSet>) ...)
```

This second formula highlights how the ConnectivityMatrix is built by pairs of LinkSet objects identifying the internal connectivity capability due to internal optical node constraint(s). It's essentially binary information and tell if a wavelength or a set of wavelengths can go from an input port to an output port.

As an additional note, ConnectivityMatrix belongs to node information, is uniquely identified by advertising node and is a static information. Dynamic information related to the actual state of connections is available through specific extension to link information.

The [RFC7446] introduces the concept of ResourceBlockInfo and ResourcePool for the WSON nodes. The resource block is a collection of resources behaving in the same way and having similar characteristics. The ResourceBlockInfo is defined as follow:

```
<ResourceBlockInfo> ::= <ResourceBlockSet> [<InputConstraints>]  
    [<ProcessingCapabilities>] [<OutputConstraints>]
```

The usage of resource block and resource pool is an efficient way to model constrains within a WSON node.

## 5. Optical Impairment Information Model

The idea behind this document is to put optical impairment parameters into categories and extend the information model already defined for impairment-free WSONs. The three categories are:

- o Node Information. The concept of connectivity matrix is reused and extended to introduce an impairment matrix, which represents the impairments suffered on the internal path between two ports. In addition, the concept of Resource Block is also reused and extended to provide an efficient modelization of per-port impairment.
- o Link Information representing impairment information related to a specific link or hop.
- o Path Information representing the impairment information related to the whole path.

All the above three categories will make use of a generic container, the Impairment Vector, to transport optical impairment information.

This information model however will allow to add additional parameters beyond the one defined by [ITU.G680] in order to support additional computational models. This mechanism could eventually be applicable to both linear and non-linear parameters.

This information model makes the assumption that each optical node in the network is able to provide the control plane protocols with its own parameter values. However, no assumption is made on how the optical nodes get those value information (e.g., internally computed, provisioned by a network management system, etc.). To this extent, the information model intentionally ignores all internal detailed parameters that are used by the formulas of the Optical Computational Model (i.e., "transfer function") and simply provides the object containers to carry results of the formulas.

### 5.1. The Optical Impairment Vector

Optical Impairment Vector (OIV) is defined as a list of optical parameters to be associated to a WSON node or a WSON link. It is defined as:

```
<OIV> ::= ([<LabelSet>] <OPTICAL_PARAM>) ...
```

The optional LabelSet object enables wavelength dependency property as per Table 1. LabelSet has its definition in [RFC7579].

OPTICAL\_PARAM. This object represents an optical parameter. The Impairment vector can contain a set of parameters as identified by [ITU.G697] since those parameters match the terms of the linear impairments computational models provided by [ITU.G680]. This information model does not speculate about the set of parameters (since defined elsewhere, e.g. ITU-T), however it does not preclude extensions by adding new parameters.

## 5.2. Node Information

### 5.2.1. Impairment Matrix

Impairment matrix describes a list of the optical parameters that applies to a network element as a whole or ingress/egress port pairs of a network element. Wavelength dependency property of optical parameters is also considered.

```
ImpairmentMatrix ::= <MatrixID> <ConnType>
  ((<LinkSet> <LinkSet> <OIV>) ...)
```

Where:

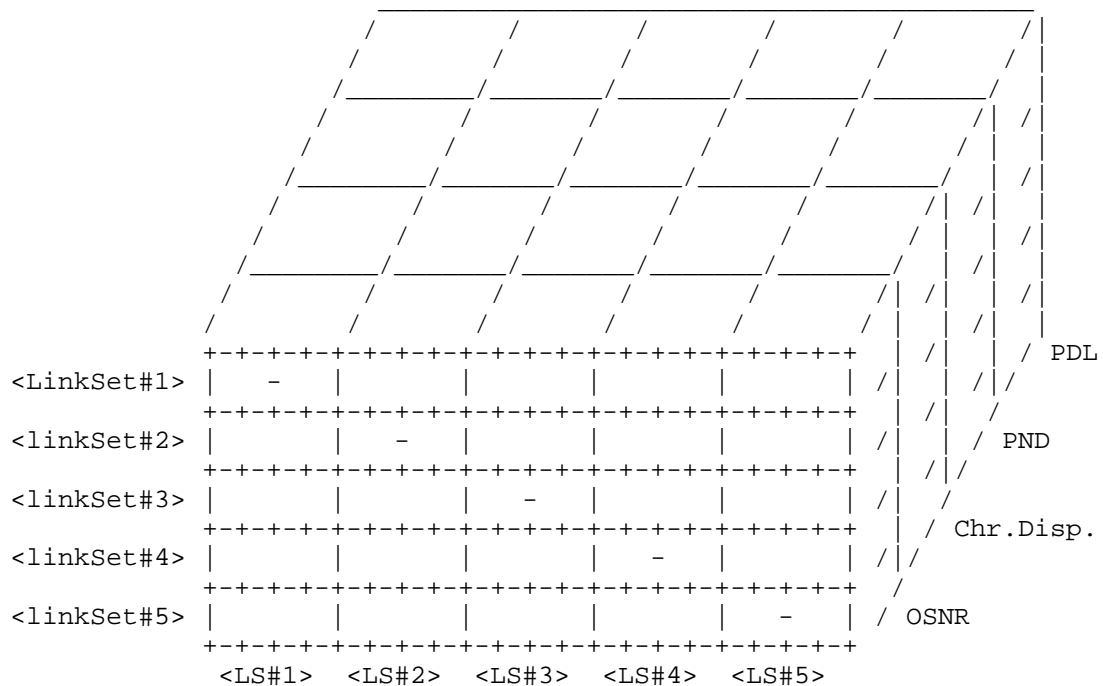
MatrixID. This ID is a unique identifier for the matrix. It shall be unique in scope among connectivity matrices defined in [RFC7446] and impairment matrices defined here.

ConnType. This number identifies the type of matrix and it shall be unique in scope with other values defined by impairment-free WSOON documents.

LinkSet. Same object definition and usage as [RFC7579]. The pairs of LinkSet identify one or more internal node constrain.

OIV. The Optical Impairment Vector defined above.

The model can be represented as a multidimensional matrix shown in the following picture



The connectivity matrix from [RFC7579] is only a two dimensional matrix, containing only binary information, through the LinkSet pairs. In this model, a third dimension is added by generalizing the binary information through the Optical Impairment Vector associated with each LinkSet pair. Optical parameters in the picture are reported just as an example: proper list and encoding shall be defined by other documents.

This representation shows the most general case however, the total amount of information transported by control plane protocols can be greatly reduced by proper encoding when the same set of values apply to all LinkSet pairs.

#### 5.2.2. Impairment Resource Block Information

This information model reuses the definition of Resource Block Information adding the associated impairment vector.

```
ResourceBlockInfo ::= <ResourceBlockSet> [<InputConstraints>]
  [<ProcessingCapabilities>] [<OutputConstraints>] [<OIV>]
```

The object ResourceBlockInfo is then used as specified within [RFC7446].

### 5.3. Link Information

For the list of optical parameters associated to the link, the same approach used for the node-specific impairment information can be applied. The link-specific impairment information is extended from [RFC7446] as the following:

```
<DynamicLinkInfo> ::= <LinkID> <AvailableLabels>  
                        [<SharedBackupLabels>] [<OIV>]
```

DynamicLinkInfo is already defined in [RFC7446] while OIV is the Optical Impairment Vector is defined in the previous section.

### 5.4. Path Information

There are cases where the optical impairments can only be described as a constraint on the overall end to end path. In such case, the optical impairment and/or parameter, cannot be derived (using a simple function) from the set of node / link contributions.

An equivalent case is the option reported by [RFC6566] on IV-Candidate paths where, the control plane knows a list of optically feasible paths so a new path setup can be selected among that list. Independent from the protocols and functions combination (i.e. RWA vs. Routing vs. PCE), the IV-Candidates imply a path property stating that a path is optically feasible.

```
<PathInfo> ::= <OIV>
```

[EDITOR NOTE: section to be completed, especially to evaluate protocol implications. Likely resemble to RSVP ADSPEC].

## 6. Encoding Considerations

Details about encoding will be defined in a separate document [I-D.martinelli-ccamp-wson-iv-encode] however worth remembering that, within [ITU.G697] Appendix V, ITU already provides a guideline for encoding some optical parameters.

In particular [ITU.G697] indicates that each parameter shall be represented by a 32 bit floating point number.



Values for optical parameters are provided by optical node and it could provide by direct measurement or from some internal computation starting from indirect measurement. In such cases, it could be useful to understand the variance associated with the value of the optical parameter hence, the encoding shall provide the possibility to include a variance as well.

This kind of information will enable IA-RWA process to make some additional considerations on wavelength feasibility. [RFC6566] Section 4.1.3 reports some considerations regarding this degree of confidence during the impairment validation process.

## 7. Control Plane Architectures

This section briefly describes how the definitions contained in this information model will match the architectural options described by [RFC6566].

The first assumption is that the WSON GMPLS extensions are available and operational. To such extent, the WSON-RWA will provide the following information through its path computation (and RWA process):

- o The wavelengths connectivity, considering also the connectivity constraints limited by reconfigurable optics, and wavelengths availability.
- o The interface compatibility at the physical level.
- o The Optical-Elettro-Optical (OEO) availability within the network (and related physical interface compatibility). As already stated by the framework this information it's very important for impairment validation:
  - A. If the IV functions fail (path optically infeasible), the path computation function may use an available OEO point to find a feasible path. In normally operated networks OEO are mainly uses to support optically unfeasible path than mere wavelength conversion.
  - B. The OEO points reset the optical impairment information since a new light is generated.

### 7.1. IV-Centralized

Centralized IV process is performed by a single entity (e.g., a PCE). Given sufficient impairment information, it can either be used to provide a list of paths between two nodes, which are valid in terms of optical impairments. Alternatively, it can help validate whether

a particular selected path and wavelength is feasible or not. This requires distribution of impairment information to the entity performing the IV process.

This Information Model doesn't make any hypothesis on distribution method for optical parameters but only defines the essential build blocks. A centralized entity may get knowledge of required information through routing protocols or other mechanism such as BGP-LS.

## 7.2. IV-Distributed

Assuming the information model is implemented through a routing protocol, every node in the WSON network shall be able to perform an RWA-IV function.

The signalling phase may provide additional checking as others traffic engineering parameters.

## 8. Acknowledgements

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## 9. IANA Considerations

This document does not contain any IANA requirement.

## 10. Security Considerations

This document defines an information model for impairments in optical networks. If such a model is put into use within a network it will by its nature contain details of the physical characteristics of an optical network. Such information would need to be protected from intentional or unintentional disclosure.

## 11. References

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## Appendix A. FAQ

### A.1. Why the Application Code does not suffice for Optical Impairment Validation?

Application Codes are encoded within GMPLS WSON protocol through the Optical Interface Class as defined in [RFC7446].

The purpose of the Application Code in RWA is simply to assess the interface compatibility: same Application Code means that two interfaces can have an LSP connecting the two.

Application Codes contain other information useful for IV process (e.g., see the list of parameters) so they are required however Computational Models requires more parameters to assess the path feasibility.

## A.2. Are DWDM network multivendor?

According to [ITU.G680] "Situation 1" the DWDM line segments are single are single vendor but an LSP can make use of different data planes entities from different vendors. For example: DWDM interfaces (represented in the control plane through the Optical Interface Class) from a vendor and network elements described by Stutation 1 from another vendor.

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Information Model for Wavelength Switched Optical Networks (WSONs) with  
Impairments Validation  
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Abstract

This document defines an information model to support Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) functionality. This information model extends the information model for impairment-free RWA process in WSON to facilitate computation of paths where optical impairment constraints need to be considered.

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## 1. Introduction

In the context of Wavelength Switched Optical Network (WSON), [RFC6163] describes the basic framework for a GMPLS and PCE-based Routing and Wavelength Assignment (RWA) control plane. The



associated information model [RFC7446] defines information/parameters required by an RWA process without optical impairment considerations.

There are cases of WSON where optical impairments play a significant role and are considered as important constraints. The framework document [RFC6566] defines the problem scope and related control plane architectural options for the Impairment Aware RWA (IA-RWA) operation. Options include different combinations of Impairment Validation (IV) and RWA functions in term of different combination of control plane functions (i.e., PCE, Routing, Signaling).

A Control Plane with RWA-IA will not be able to solve the optical impairment problem in a detailed and exhaustive way, however, it may take advantage of some data plane knowledge to make better decisions during its path computing phase. The final outcome will be a path, instantiated through a wavelength in the data plane, that has a "better chance" to work than that path were calculated without IA information. "Better chance" means that path setup may still fail and the GMPLS control plane will follow its usual procedures upon errors and failures. A control plane will not replace a the network design phase that remains a fundamental step for DWDM Optical Networks. As the non-linear impairments which need to be considered in the calculation of an optical path will be vendor-dependent, the parameters considered in this document is not an exhaustive list.

This document provides an information model for the impairment aware case to allow the impairment validation function implemented in the control plane or enabled by control plane available information. This model goes in addition to [RFC7446] and shall support any control plane architectural option described by the framework document (see sections 4.2 and 4.3 of [RFC6566]) where a set of combinations of control plane functions vs. IV function is provided.

## 2. Definitions, Applicability and Properties

This section provides some concepts to help understand the model and to make a clear separation from data plane definitions (ITU-T recommendations). The first sub-section provides definitions while the Applicability sections uses the defined definitions to scope this document.

### 2.1. Definitions

- o Computational Model / Optical Computational Model.  
Defined by ITU standard documents (e.g. [ITU.G680]). In this context we look for models able to compute optical impairments for a given lightpath.

- o Information Model.  
Defined by IETF (this document) and provides the set of information required by control plane to apply the Computational Model.
- o Level of Approximation.  
This concept refers to the Computational Model as it may compute optical impairment with a certain level of uncertainty. This level is generally not measured but [RFC6566] Section 4.1.1 provides a rough classification about it.
- o Feasible Path.  
It is the output of the C-SPF with RWA-IV capability. It's an optical path that satisfies optical impairment constraints. The path, instantiated through wavelength(s), may actually work or not work depending of the level of approximation.
- o Existing Service Disruption.  
An effect known to optical network designers is the cross-interaction among spectrally adjacent wavelengths: an existing wavelength may experience increased BER due to the setup of an adjacent wavelength. Solving this problem is a typical optical network design activity. Just as an example, a simple solution is adding optical margins (e.g., additional OSNR), although complex and detailed methods exist.
- o DWDM Line Segments.  
[ITU.G680] provides definition and picture for the "Situation 1" DWDM Line segments: " Situation 1 - The optical path between two consecutive 3R regenerators is composed of DWDM line segments from a single vendor and OADMs and PXC's from another vendor". Document [RFC6566] Figure 1 shows an LSP composed by two DWDM line segments according to [ITU.G680] definition.

## 2.2. Applicability

This document targets at Scenario C defined in [RFC6566] section 4.1.1. as approximate impairment estimation. The Approximate concept refer to the fact that this Information Model covers information mainly provided by [ITU.G680] Computational Model.

Computational models having no or little approximation, referred as IV-Detailed in the [RFC6566], currently does not exist in term of ITU-T recommendation. They generally deal with non-linear optical impairment and are usually vendor specific.

The Information Model defined in this document does not speculate about the mathematical formulas used to fill up information model

parameters, hence it does not preclude changing the computational model. At the same time, the authors do not believe this Information Model is exhaustive and if necessary further documents will cover additional models after they become available.

The result of RWA-IV process implementing this Information Model is a path (and a wavelength in the data plane) that has better chance to be feasible than if it was computed without any IV function. The Existing Service Disruption, as per the definition above, would still be a problem left to a network design phase.

### 2.3. Properties

An information model may have several attributes or properties that need to be defined for each optical parameter made available to the control plane. The properties will help to determine how the control plane can deal with a specific impairment parameter, depending on architectural options chosen within the overall impairment framework [RFC6566]. In some case, properties value will help to identify the level of approximation supported by the IV process.

- o Time Dependency

This identifies how an impairment parameter may vary with time. There could be cases where there is no time dependency, while in other cases there may be need of re-evaluation after a certain time. In this category, variations in impairments due to environmental factors such as those discussed in [ITU.GSUP47] are considered. In some cases, an impairment parameter that has time dependency may be considered as a constant for approximation. In this information model, we do neglect this property.

- o Wavelength Dependency

This property identifies if an impairment parameter can be considered as constant over all the wavelength spectrum of interest or not. Also in this case a detailed impairment evaluation might lead to consider the exact value while an approximation IV might take a constant value for all wavelengths. In this information model, we consider both case: dependency / no dependency on a specific wavelength. This property appears directly in the information model definitions and related encoding.

- o Linearity

As impairments are representation of physical effects, there are some that have a linear behaviour while other are non-linear. Linear approximation is in scope of Scenario C of [RFC6566]. During the impairment validation process, this property implies that the optical effect (or quantity) satisfies the superposition

principle, thus a final result can be calculated by the sum of each component. The linearity implies the additivity of optical quantities considered during an impairment validation process. The non-linear effects in general do not satisfy this property. The information model presented in this document however, easily allow introduction of non-linear optical effects with a linear approximated contribution to the linear ones.

o Multi-Channel

There are cases where a channel's impairments take different values depending on the aside wavelengths already in place, this is mostly due to non-linear impairments. The result would be a dependency among different LSPs sharing the same path. This information model do not consider this kind of property.

The following table summarise the above considerations where in the first column reports the list of properties to be considered for each optical parameter, while the second column states if this property is taken into account or not by this information model.

Property	Info Model Awareness
Time Dependency	no
Wavelength Dependency	yes
Linearity	yes
Multi-channel	no

Table 1: Optical Impairment Properties

### 3. ITU-T List of Optical Parameters

As stated by Section 2.2 this Information Model does not intend to be exhaustive and targets an approximate computational model although not precluding future evolutions towards more detailed or different impairments estimation methods.

On the same line, ITU SG15/Q6 provides (through [LS78]) a list of optical parameters with following observations:

- (a) the problem of calculating the non-linear impairments in a multi-vendor environment is not solved. The transfer functions works only for the so called [ITU.G680] "Situation 1".
- (b) The generated list of parameters is not exhaustive however provide a guideline for control plane optical impairment awareness.

In particular, [ITU.G680] contains many parameters that would be required to estimate linear impairments. Some of the Computational Models defined within [ITU.G680] requires parameters defined in other documents like [ITU.G671]. The purpose of the list here below makes this match between the two documents.

[ITU.G697] defines parameters can be monitored in an optical network. This Information Model and associated encoding document will reuse [ITU.G697] parameters identifiers and encoding for the purpose of path computation.

The list of optical parameters starts from [ITU.G680] Section 9 which provides the optical computational models for the following p:

G-1 OSNR. Section 9.1

G-2 Chromatic Dispersion (CD). Section 9.2

G-3 Polarization Mode Dispersion (PMD). Section 9.3

G-4 Polarization Dependent Loss (PDL). Section 9.3

In addition to the above, the following list of parameters has been mentioned by [LS78]:

- L-1 "Channel frequency range", [ITU.G671]. This parameter is part of the application code and encoded through Optical Interface Class as defined in [RFC7446].
- L-2 "Modulation format and rate". This parameter is part of the application code and encoded through Optical Interface Class as defined in [RFC7446].
- L-3 "Channel power". Required by G-1.
- L-4 "Ripple". According to [ITU.G680], this parameter can be taken into account as additional OSNR penalty.
- L-5 "Channel signal-spontaneous noise figure", [ITU.G680]. Required by OSNR calculation (see G-1) above.
- L-6 "Channel chromatic dispersion (for fibre segment or network element)". Already in G-2 above.
- L-7 "Channel local chromatic dispersion (for a fibre segment)". Already in G-2 above (since consider both local and fiber dispersions).

- L-8 "Differential group delay (for a network element)", [ITU.G671]. Required by G-3.
- L-9 "Polarisation mode dispersion (for a fibre segment)", [ITU.G650.2], [ITU.G680]. Defined above as G-3.
- L-10 "Polarization dependent loss (for a network element)", [ITU.G671] and [ITU.G680]. Defined above as G-4.
- L-11 "Reflectance". From [ITU.G671] Section 3.2.2.37 is the ratio of reflected power  $P_r$  to incident power  $P_i$  at a given port of a passive component, for given conditions of spectral composition, polarization and geometrical distribution. Generally expressed in dB. Might be monitored in some critical cases. We neglect this effect as first approximation.
- L-12 "Channel Isolation". From [ITU.G671] Section 3.2.2.2 (Adjacent Channel Isolation) and Section 3.2.2.29 (Non Adjacent Channel Isolation). Document [ITU.GSUP39] provide the formula for calculation as channel cross-talk and measure it in dB. This parameter shall be considered for path computation.
- L-13 "Channel extinction". From [ITU.G671] Section 3.2.2.9 needed for Interferometric Crosstalk. Document [ITU.GSUP39] has the formula for penalty computation. Unit of measurement is dB.
- L-14 "Attenuation coefficient (for a fibre segment)". Document [ITU.G650.1] Section 3.6.2. The unit of measure is dB. This is a typical link parameter (as associated to a fiber).
- L-15 "Non-linear coefficient (for a fibre segment)", [ITU.G650.2]. Required for Non-Linear Optical Impairment Computational Models. Neglected by this document.

The final list of parameters is G-1, G-2, G-3, G-4, L-3, L-4, L-5, L-8, L-12, L-13, L-14.

#### 4. Background from WSON-RWA Information Model

In this section we report terms already defined for the WSON-RWA (impairment free) as in [RFC7446] and [RFC7579]. The purpose is to provide essential information that will be reused or extended for the impairment case.

In particular [RFC7446] Section 4.1 defines the ConnectivityMatrix and states that such matrix does not represent any particular internal blocking behaviour but indicates which input ports and wavelengths could possibly be connected to a particular output port.

<ConnectivityMatrix> ::= <MatrixID> <ConnType> <Matrix>

According to [RFC7579], this definition is further detailed as:

<ConnectivityMatrix> ::=  
    <MatrixID> <ConnType> ((<LinkSet> <LinkSet>) ...)

This second formula highlights how the ConnectivityMatrix is built by pairs of LinkSet objects identifying the internal connectivity capability due to internal optical node constraint(s). It's essentially binary information and tell if a wavelength or a set of wavelengths can go from an input port to an output port.

As an additional note, ConnectivityMatrix belongs to node information, is uniquely identified by advertising node and is a static information. Dynamic information related to the actual state of connections is available through specific extension to link information.

The [RFC7446] introduces the concept of ResourceBlockInfo and ResourcePool for the WSON nodes. The resource block is a collection of resources behaving in the same way and having similar characteristics. The ResourceBlockInfo is defined as follow:

<ResourceBlockInfo> ::= <ResourceBlockSet> [<InputConstraints>]  
    [<ProcessingCapabilities>] [<OutputConstraints>]

The usage of resource block and resource pool is an efficient way to model constraints within a WSON node.

## 5. Optical Impairment Information Model

The idea behind this document is to put optical impairment parameters into categories and extend the information model already defined for impairment-free WSONs. The three categories are:

- o Node Information. The concept of connectivity matrix is reused and extended to introduce an impairment matrix, which represents the impairments suffered on the internal path between two ports. In addition, the concept of Resource Block is also reused and extended to provide an efficient representation of per-port impairment.
- o Link Information representing impairment information related to a specific link or hop.
- o Path Information representing the impairment information related to the whole path.

All the above three categories will make use of a generic container, the Impairment Vector, to transport optical impairment information.

This information model however will allow however to add additional parameters beyond the one defined by [ITU.G680] in order to support additional computational models. This mechanism could eventually be applicable to both linear and non-linear parameters.

This information model makes the assumption that the each optical node in the network is able to provide the control plane protocols with its own parameter values. However, no assumption is made on how the optical nodes get those value information (e.g., internally computed, provisioned by a network management system, etc.). To this extent, the information model intentionally ignores all internal detailed parameters that are used by the formulas of the Optical Computational Model (i.e., "transfer function") and simply provides the object containers to carry results of the formulas.

### 5.1. The Optical Impairment Vector

Optical Impairment Vector (OIV) is defined as a list of optical parameters to be associated to a WSON node or a WSON link. It is defined as:

```
<OIV> ::= ([<LabelSet>] <OPTICAL_PARAM>) ...
```

The optional LabelSet object enables wavelength dependency property as per Table 1. LabelSet has its definition in [RFC7579].

OPTICAL\_PARAM. This object represents an optical parameter. The Impairment vector can contain a set of parameters as identified by [ITU.G697] since those parameters match the terms of the linear impairments computational models provided by [ITU.G680]. This information model does not speculate about the set of parameters (since defined elsewhere, e.g. ITU-T), however it does not preclude extensions by adding new parameters.

### 5.2. Node Information

#### 5.2.1. Impairment Matrix

Impairment matrix describes a list of the optical parameters that applies to a network element as a whole or ingress/egress port pairs of a network element. Wavelength dependency property of optical parameters is also considered.

```
ImpairmentMatrix ::= <MatrixID> <ConnType>  
    ((<LinkSet> <LinkSet> <OIV>) ...)
```



Where:

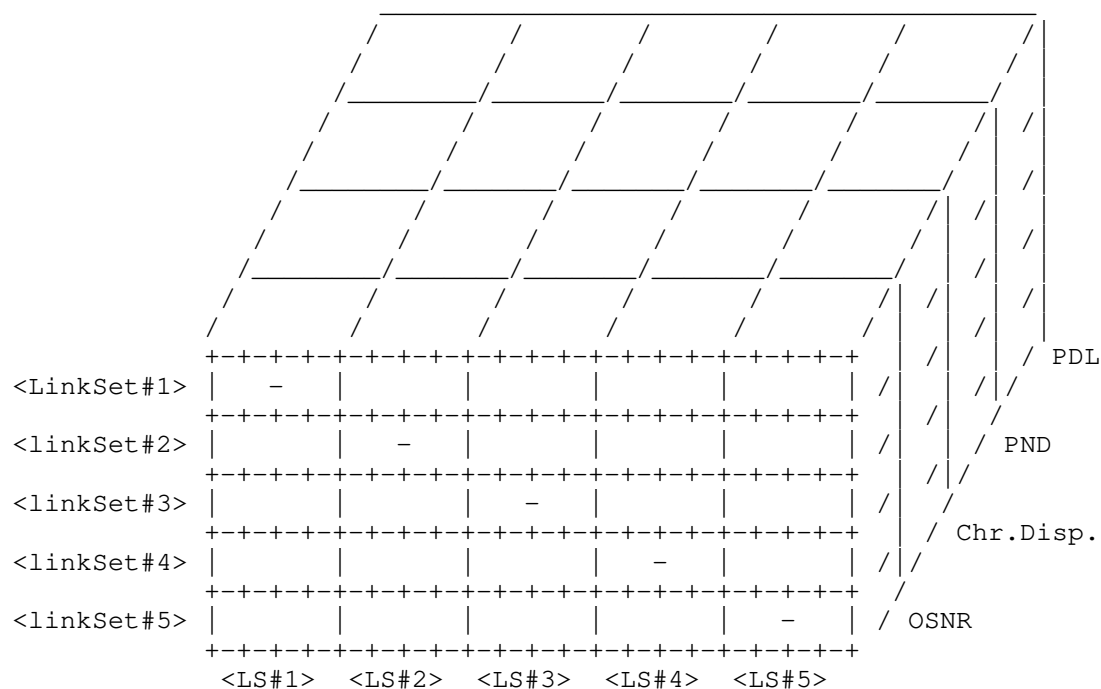
**MatrixID.** This ID is a unique identifier for the matrix. It shall be unique in scope among connectivity matrices defined in [RFC7446] and impairment matrices defined here.

**ConnType.** This number identifies the type of matrix and it shall be unique in scope with other values defined by impairment-free WSON documents.

**LinkSet.** Same object definition and usage as [RFC7579]. The pairs of LinkSet identify one or more internal node constrain.

**OIV.** The Optical Impairment Vector defined above.

The model can be represented as a multidimensional matrix shown in the following picture



The connectivity matrix from [RFC7579] is only a two dimensional matrix, containing only binary information, through the LinkSet

pairs. In this model, a third dimension is added by generalizing the binary information through the Optical Impairment Vector associated with each LinkSet pair. Optical parameters in the picture are reported just as an example: proper list and encoding shall be defined by other documents.

This representation shows the most general case however, the total amount of information transported by control plane protocols can be greatly reduced by proper encoding when the same set of values apply to all LinkSet pairs.

#### 5.2.2. Impairment Resource Block Information

This information model reuses the definition of Resource Block Information adding the associated impairment vector.

```
ResourceBlockInfo ::= <ResourceBlockSet> [<InputConstraints>]  
                        [<ProcessingCapabilities>] [<OutputConstraints>] [<OIV>]
```

The object ResourceBlockInfo is then used as specified within [RFC7446].

#### 5.3. Link Information

For the list of optical parameters associated to the link, the same approach used for the node-specific impairment information can be applied. The link-specific impairment information is extended from [RFC7446] as the following:

```
<DynamicLinkInfo> ::= <LinkID> <AvailableLabels>  
                        [<SharedBackupLabels>] [<OIV>]
```

DynamicLinkInfo is already defined in [RFC7446] while OIV is the Optical Impairment Vector is defined in the previous section.

#### 5.4. Path Information

There are cases where the optical impairments can only be described as a constraints on the overall end to end path. In such case, the optical impairment and/or parameter, cannot be derived (using a simple function) from the set of node / link contributions.

An equivalent case is the option reported by [RFC6566] on IV-Candidate paths where, the control plane knows a list of optically feasible paths so a new path setup can be selected among that list. Independent from the protocols and functions combination (i.e. RWA vs. Routing vs. PCE), the IV-Candidates imply a path property stating that a path is optically feasible.

The concept of Optical Impairment Vector (OIV) might be used or extended to report optical impairment information at path level however this is case is left for future studies.

## 6. Encoding Considerations

Details about encoding will be defined in a separate document [I-D.ietf-ccamp-wson-iv-encode] however worth remembering that, within [ITU.G697] Appendix V, ITU already provides a guideline for encoding some optical parameters.

In particular [ITU.G697] indicates that each parameter shall be represented by a 32 bit floating point number.

Values for optical parameters are provided by optical node and it could provide by direct measurement or from some internal computation starting from indirect measurement. In such cases, it could be useful to understand the variance associated with the value of the optical parameter hence, the encoding shall provide the possibility to include a variance as well.

This kind of information will enable IA-RWA process to make some additional considerations on wavelength feasibility. [RFC6566] Section 4.1.3 reports some considerations regarding this degree of confidence during the impairment validation process.

## 7. Control Plane Architectures

This section briefly describes how the definitions contained in this information model will match the architectural options described by [RFC6566]. This section does not suggest suggested any specific protocol option.

The assumption is that WSON GMPLS extensions are available and operational. To such extent, the WSON-RWA will provide the following information through its path computation (and RWA process):

- o The wavelengths connectivity, considering also the connectivity constraints limited by reconfigurable optics, and wavelengths availability.
- o The interface compatibility at the physical level.
- o The Optical-Electro-Optical (OEO) availability within the network (and related physical interface compatibility). As already stated by the framework this information it's very important for impairment validation:

- A. If the IV functions fail (path optically infeasible), the path computation function may use an available OEO point to find a feasible path. In normally operated networks OEO are mainly used to support optically unfeasible path than mere wavelength conversion.
- B. The OEO points reset the optical impairment information since a new light is generated.

#### 7.1. IV-Centralized

Centralized IV process is performed by a single entity (e.g. a PCE or other external entities). Given sufficient impairment information, it can either be used to provide a list of paths between two nodes, which are valid in terms of optical impairments. Alternatively, it can help validate whether a particular selected path and wavelength is feasible or not.

Centralized IV functions requires exchange of impairment information to the entity performing the IV process from network nodes. This information exchange may requires implementation of this information model within an existing protocol (i.e. routing protocol vs PCEP vs BGP-LS vs others).

#### 7.2. IV-Distributed

Assuming the information model is implemented through a routing protocol, every node in the WSOON network shall be able to perform an RWA-IV function.

The signalling phase may provide additional checking as others traffic engineering parameters.

### 8. Acknowledgements

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## 10. IANA Considerations

This document does not contain any IANA requirement.

## 11. Security Considerations

This document defines an information model for impairments in optical networks. If such a model is put into use within a network it will by its nature contain details of the physical characteristics of an

optical network. Such information would need to be protected from intentional or unintentional disclosure.

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## Appendix A. FAQ

### A.1. Why the Application Code does not suffice for Optical Impairment Validation?

Application Codes are encoded within GMPLS WSON protocol through the Optical Interface Class as defined in [RFC7446].

The purpose of the Application Code in RWA is simply to assess the interface compatibility: same Application Code means that two interfaces can have an LSP connecting the two.

Application Codes contain other information useful for IV process (e.g., see the list of parameters) so they are required however Computational Models requires more parameteres to assess the path feasibility.

#### A.2. Are DWDM network multivendor?

According to [ITU.G680] "Situation 1" the DWDM line segments are single are single vendor but an LSP can make use of different data planes entities from different vendors. For example: DWDM interfaces (represented in the control plane through the Optical Interface Class) from a vendor and network elements described by Stutation 1 from another vendor.

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## A Yang Data Model for WSON Optical Networks

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### Abstract

This document provides a YANG data model for the routing and wavelength assignment (RWA) TE topology in wavelength switched optical networks (WSONs).

### Status of this Memo

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#### 1. Introduction

This document provides a YANG data model for the routing and wavelength assignment (RWA) Traffic Engineering (TE) topology in wavelength switched optical networks (WSONs). The YANG model described in this document is a WSON 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]. This document augments the the generic TE topology draft [TE-TOP0].

What is not in scope of this document is both impairment-aware WSON and flex-grid.

## 2. YANG Model (Tree Structure)

```
module: ietf-wson-topology
  augment /nd:networks/nd:network/nd:network-types:
    +--rw wson-topology!
  augment /nd:networks/nd:network/nd:node/tet:te/tet:te-node-
attributes/tet:connectivity-matrices/tet:connectivity-matrix:
    +--rw matrix-interface* [in-port-id]
      +--rw in-port-id      wson-interface-ref
      +--rw out-port-id?    wson-interface-ref
  augment /nd:networks/nd:network/lnk:link/tet:te/tet:te-link-attributes:
    +--rw channel-max?      int32
    +--rw default-frequency? decimal64
    +--rw channel-spacing?  decimal64
    +--rw wavelength-available-bitmap* binary
  augment /nd:networks/nd:network/nd:node/tet:te/tet:te-node-attributes:
    +--rw wson-node
      | +--rw device-type?    devicetype
      | +--rw dir?            directionality
      | +--rw interfaces* [name]
      |   +--rw name          string
      |   +--rw port-number?  uint32
      |   +--rw input-port?   boolean
      |   +--rw output-port?  boolean
      |   +--rw description?  string
    +--rw resource-pool* [resource-pool-id]
      +--rw resource-pool-id  uint32
      +--rw pool-state?      boolean
      +--rw matrix-interface* [in-port-id]
        +--rw in-port-id      wson-interface-ref
        +--rw out-port-id?    wson-interface-ref
```

### 3. WSON-RWA YANG Model

```
<CODE BEGINS> file "ietf-wson-topology@2017-07-03.yang"

module ietf-wson-topology {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-wson-topology";

  prefix "wson";

  import ietf-network {
    prefix "nd";
  }

  import ietf-network-topology {
    prefix "lnk";
  }

  import ietf-inet-types {
    prefix "inet";
  }
  import ietf-te-topology {
    prefix "tet";
  }

  organization
    "IETF CCAMP Working Group";

  contact
    "Editor:   Young Lee   <leeyoung@huawei.com>";

  description
    "This module contains a collection of YANG definitions for
    RWA WSON.

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    authors of the code.  All rights reserved.

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    without modification, is permitted pursuant to, and subject
    to the license terms contained in, the Simplified BSD
```

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(<http://trustee.ietf.org/license-info>).";

```
revision 2017-07-03 {
  description
    "version 7.";

  reference
    "RFC XXX: A Yang Data Model for WSON Optical Networks ";
}

typedef wson-topology-id {
  type inet:uri;
  description
    "The WSON Topology ID";
}

typedef wson-node-id {
  type inet:ip-address;
  description
    "The WSON Node ID";
}

typedef devicetype {
  type enumeration {
    enum adm {
      value 1;
      description
        "Device is ADM";
    }

    enum roadm {
      value 2;
      description
        "Device is ROAMD/OXC";
    }
  }
  description
    "device type: fixed (ADM) or switched (ROADM/OXC)";
}

typedef directionality {
  type enumeration {
    enum bidir {
      value 0;
      description
        "bi-directional";
    }
  }
}
```

```

        enum input {
            value 1;
            description
                "input direction";
        }
        enum output {
            value 2;
            description
                "output direction";
        }
    }
    description
        "The directionality of link set";
}

typedef wson-interface-ref {
    type leafref {
        path "/nd:networks/nd:network/nd:node/tet:te/"
        + "tet:te-node-attributes/wson:wson-node/"
        + "wson:interfaces/wson:name";
    }
    description
        "This type is used by data models that need to
        reference WSON interface.";
}

grouping wson-topology-type {
    description "wson-topology type";
    container wson-topology {
        presence "indicates a topology of wson";
        description
            "Container to identify wson topology type";
    }
}

grouping wson-node-attributes {
    description "wson node attributes";
    container wson-node {
        description "WSON node attributes.";
        leaf device-type {
            type devicetype;
            description
                "device type: fixed (ADM) or switched
                (ROADM/OXC)";
        }
        leaf dir {
            type directionality;
            description
                "bi-directionality or input or output

```

```
        of link set";
    }
    list interfaces {
        key "name";
        unique "port-number"; // TODO Puerto y TP ID
        description "List of interfaces contained in the node";
        uses node-interface;
    }
}

grouping node-interface {
    description "node interface definition";
    leaf name {
        type string;
        description "Interface name";
    }
    leaf port-number {
        type uint32;
        description "Number of the port used by the interface";
    }
    leaf input-port {
        type boolean;
        description "Determines if the port is an input port";
    }
    leaf output-port {
        type boolean;
        description
            "Determines if the port is an output port";
    }
    leaf description {
        type string;
        description "Description of the interface";
    }
}

grouping available-wavelength {
    description "describe available wavelengths";
    leaf-list wavelength-available-bitmap {
        type binary;
        description
            "array of bits (i.e., bitmap) that indicates
            if a wavelength is available or not on each
            channel.";
    }
}

grouping wson-link-attributes {
    description "Set of WSON link attributes";
}
```



```

        leaf channel-max {
            type int32;
            description "Maximum Number of OCh channels available
by the node";
        }
        leaf default-frequency {
            type decimal64 {
                fraction-digits 5;
            }
            units THz;
            default 193.1;
            description "Default Central Frequency";
        }
        leaf channel-spacing {
            type decimal64 {
                fraction-digits 5;
            }
            units GHz;
            description "This is fixed channel spacing for WSON,
e.g, 12.5, 25, 50, 100, ..";
        }
    }

    grouping wson-connectivity-matrix {
        description "wson connectivity matrix";
        list matrix-interface {
            key "in-port-id";

            description
                "matrix-interface describes input-ports
                and out-ports around a connectivity
                matrix";

            leaf in-port-id {
                type wson-interface-ref;
                description
                    "The reference to in-port";
            }

            leaf out-port-id {
                type wson-interface-ref;
                description
                    "The reference to out-port";
            }
        }
    }

    grouping resource-pool-attributes {
        description "resource pool describes regeneration or wave converter"
;

```

```
list resource-pool {
  key "resource-pool-id";
  description
    "The resource pool list";

  leaf resource-pool-id {
    type uint32;
    description
      "The resource pool ID";
  }

  leaf pool-state {
    type boolean;
    description
      "TRUE is state UP; FALSE is state down";
  }

  uses wson-connectivity-matrix;
}

augment "/nd:networks/nd:network/nd:network-types" {
  description "wson-topology augmented";
  uses wson-topology-type;
}

augment "/nd:networks/nd:network/nd:node/tet:te"
+ "/tet:te-node-attributes/tet:connectivity-matrices"
+ "/tet:connectivity-matrix" {
  when "/nd:networks/nd:network/nd:network-types"
  + "/wson-topology" {
    description
      "This augment is only valid for
      WSON connectivity matrix.";
  }
  description "WSON connectivity matrix state augmentation";
  uses wson-connectivity-matrix;
}

augment "/nd:networks/nd:network/lnk:link/tet:te"
+ "/tet:te-link-attributes" {
  when "/nd:networks/nd:network/nd:network-types"
  + "/wson-topology" {
    description
      "This augment is only valid for WSON.";
  }
  description "WSON Link augmentation.";
```

```
        uses wson-link-attributes;
        uses available-wavelength;
    }

    augment "/nd:networks/nd:network/nd:node/tet:te"
      + "/tet:te-node-attributes" {
      when "/nd:networks/nd:network/nd:network-types"
        + "/wson-topology" {
        description
          "This augment is only valid for WSON.";
      }
      description "WSON Node augmentation.";

      uses wson-node-attributes;
      uses resource-pool-attributes;
    }
  }
<CODE ENDS>
```

#### 4. Security Considerations

TDB

#### 5. IANA Considerations

TDB

#### 6. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.

## 7. References

### 7.1. Normative References

[TE-TOPO] X. Liu, et al., "YANG Data Model for TE Topologies", work in progress: draft-ietf-teas-yang-te-topo.

### 7.2. Informative References

[RFC7446] Y. Lee, G. Bernstein, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

[RFC7579] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "General Network Element Constraint Encoding for GMPLS Controlled Networks", RFC 7579, June 2015.

[RFC7581] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, June 2015.

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A YANG Data Model for WSON (Wavelength Switched Optical Networks)  
draft-ietf-ccamp-wson-yang-28

## Abstract

This document provides a YANG data model for the routing and wavelength assignment (RWA) TE topology in wavelength switched optical networks (WSONs). The YANG data model defined in this document conforms to the Network Management Datastore Architecture (NMDA).

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## 1. Introduction

This document provides a YANG data model for the routing and wavelength assignment (RWA) Traffic Engineering (TE) topology in transparent wavelength switched optical networks (WSONs). The YANG model described in this document is a WSON 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].

[ITU-Tg6982] defines amplified multichannel dense wavelength division multiplexing applications with single channel optical interfaces. The YANG data model defined in this document refers to the standard application mode defined in [ITU-Tg6982].

What is not in scope of this document is both impairment-aware optical networks and flexi-grid. Refer to [I-D.ietf-ccamp-optical-impairment-topology-yang] for impairment-aware optical network topology model and [I-D.ietf-ccamp-flexigrid-yang] for flexi-grid optical network topology model.

Additionally, transponders and resource blocks (e.g., 3R Regeneration) models are not in the scope of this document.



This document defines one YANG model: ietf-wson-topology (Section 3). This document augments the generic TE topology draft [RFC8795].

There are multiple applications for the yang data model defined in this document. For example, nodes within the network can use the data model to capture their understanding of the overall WSON topology and expose it to a controller. A controller can further propagate the topology to other controllers. The YANG model is used by NETCONF [RFC6020], [RFC8341] or a RESTCONF [RFC8040] protocol. The YANG data model defined in this document conforms to the Network Management Datastore Architecture [RFC8342].

### 1.1. Terminology and Notations

Refer to [RFC7446] and [RFC7581] 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 document. The meaning of the symbols in these diagrams is defined in [RFC8340].

### 1.3. Prefix 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 the following table.

Prefix	YANG module	Reference
10-types	ietf-layer0-types	[ietf-ccamp-layer0-types]
wson	ietf-wson-topology	[RFCXXXX]
nw	ietf-network	[RFC8345]
nt	ietf-network-topology	[RFC8345]
tet	ietf-te-topology	[RFC8795]

Note: The RFC Editor will replace XXXX with the number assigned to the RFC once this draft becomes an RFC.

## 2. YANG Model (Tree Structure) for WSON topology

```

module: ietf-wson-topology
  augment /nw:networks/nw:network/nw:network-types/tet:te-topology:
    +--rw wson-topology!
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes:
      +--rw wson-node!
      +--rw is-reconfigurable-node?  boolean
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction:
      +--rw grid-type?  identityref
      +--rw priority?   uint8
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction:
      +--rw grid-type?  identityref
      +--rw priority?   uint8
  augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:to/tet:label-restrictions
    /tet:label-restriction:
      +--rw grid-type?  identityref

```

```

    +---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:to/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?      uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?      uint8
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:information-source-entry/tet:label-restrictions
    /tet:label-restriction:
    +---ro grid-type?    identityref
    +---ro priority?      uint8
augment /nw:networks/tet:te/tet:templates/tet:link-template
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction:
    +---rw grid-type?    identityref
    +---rw priority?      uint8
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices

```

```

        /tet:label-restrictions/tet:label-restriction
        /tet:label-start/tet:te-label/tet:technology:
+---: (wson)
    +---rw (grid-type)?
    +---: (dwdm)
    |   +---rw dwdm-n?    10-types:dwdm-n
    +---: (cwdm)
    +---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-end/tet:te-label/tet:technology:
+---: (wson)
    +---rw (grid-type)?
    +---: (dwdm)
    |   +---rw dwdm-n?    10-types:dwdm-n
    +---: (cwdm)
    +---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-step/tet:technology:
+---: (wson)
    +---rw (l0-grid-type)?
    +---: (dwdm)
    |   +---rw wson-dwdm-channel-spacing?    identityref
    +---: (cwdm)
    +---rw wson-cwdm-channel-spacing?    identityref
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:primary-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---: (wson)
    +---rw (grid-type)?
    +---: (dwdm)
    |   +---rw (single-or-super-channel)?
    |   |   +---: (single)
    |   |   |   +---rw dwdm-n?                    10-types:dwdm-n
    |   |   +---: (super)
    |   |   +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---: (cwdm)
    +---rw cwdm-n?                    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:underlay/tet:backup-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---: (wson)
    +---rw (grid-type)?

```

```

    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|       +---:(single)
|           |   +---rw dwdm-n?           10-types:dwdm-n
|       +---:(super)
|           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|       +---:(single)
|           |   +---rw dwdm-n?           10-types:dwdm-n
|       +---:(super)
|           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)

```

```

    +---ro (grid-type)?
      +---:(dwdm)
        | +---ro (single-or-super-channel)?
        |   +---:(single)
        |     | +---ro dwdm-n?          10-types:dwdm-n
        |     +---:(super)
        |       +---ro subcarrier-dwdm-n* 10-types:dwdm-n
      +---:(cwdm)
        +---ro cwdm-n?          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw dwdm-n?  10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw dwdm-n?  10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:from/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
  +---rw (l0-grid-type)?
    +---:(dwdm)
      | +---rw wson-dwdm-channel-spacing?  identityref
    +---:(cwdm)
      +---rw wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:te-node-attributes/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(wson)
  +---rw (grid-type)?

```

```

      +---:(dwdm)
      |   +---rw dwdm-n?   10-types:dwdm-n
      +---:(cwdm)
      |   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:to/tet:label-restrictions
      /tet:label-restriction/tet:label-end/tet:te-label
      /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?   10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:to/tet:label-restrictions
      /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---rw (l0-grid-type)?
+---:(dwdm)
|   +---rw wson-dwdm-channel-spacing?   identityref
+---:(cwdm)
|   +---rw wson-cwdm-channel-spacing?   identityref
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:underlay/tet:primary-path
      /tet:path-element/tet:type/tet:label/tet:label-hop
      /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?   10-types:dwdm-n
|   |   +---:(super)
|   |   |   +---rw subcarrier-dwdm-n*   10-types:dwdm-n
+---:(cwdm)
|   +---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
      /tet:te-node-attributes/tet:connectivity-matrices
      /tet:connectivity-matrix/tet:underlay/tet:backup-path
      /tet:path-element/tet:type/tet:label/tet:label-hop
      /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)

```

```

    +---rw (single-or-super-channel)?
        +---:(single)
            | +---rw dwdm-n?                10-types:dwdm-n
        +---:(super)
            +---rw subcarrier-dwdm-n*      10-types:dwdm-n
    +---:(cwdm)
        +---rw cwdm-n?                    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:optimizations/tet:algorithm
    /tet:metric/tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
        +---:(dwdm)
            | +---rw (single-or-super-channel)?
                +---:(single)
                    | +---rw dwdm-n?                10-types:dwdm-n
                +---:(super)
                    +---rw subcarrier-dwdm-n*      10-types:dwdm-n
            +---:(cwdm)
                +---rw cwdm-n?                    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:optimizations/tet:algorithm
    /tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
        +---:(dwdm)
            | +---rw (single-or-super-channel)?
                +---:(single)
                    | +---rw dwdm-n?                10-types:dwdm-n
                +---:(super)
                    +---rw subcarrier-dwdm-n*      10-types:dwdm-n
            +---:(cwdm)
                +---rw cwdm-n?                    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:te-node-attributes/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?

```



```

    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-start/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-end/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:label-restrictions/tet:label-restriction
    /tet:label-step/tet:technology:
+---:(wson)
    +---ro (l0-grid-type)?
    +---:(dwdm)
    |   +---ro wson-dwdm-channel-spacing?    identityref
    +---:(cwdm)
    |   +---ro wson-cwdm-channel-spacing?    identityref
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:underlay/tet:primary-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n

```

```

    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:underlay/tet:backup-path/tet:path-element/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n
    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n
    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:optimizations/tet:algorithm/tet:metric
    /tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |         +---ro (single-or-super-channel)?
    |         +---:(single)
    |         |         +---ro dwdm-n?                10-types:dwdm-n

```

```

    |         +---:(super)
    |         +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
    |         +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:path-properties/tet:path-route-objects
    /tet:path-route-object/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |     +---ro (single-or-super-channel)?
    |     |     +---:(single)
    |     |     |     +---ro dwdm-n?                10-types:dwdm-n
    |     |     +---:(super)
    |     |     +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |     +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |     +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |     +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(wson)
    +---ro (grid-type)?
    +---:(dwdm)
    |     +---ro dwdm-n?    10-types:dwdm-n
    +---:(cwdm)
    |     +---ro cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:from/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
    +---ro (l0-grid-type)?
    +---:(dwdm)

```

```

    | +--ro wson-dwdm-channel-spacing?  identityref
    +--:(cwdm)
      +--ro wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro dwdm-n?  10-types:dwdm-n
    +--:(cwdm)
      +--ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-end/tet:te-label
  /tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro dwdm-n?  10-types:dwdm-n
    +--:(cwdm)
      +--ro cwdm-n?  10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:to/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+--:(wson)
  +--ro (l0-grid-type)?
  +--:(dwdm)
    | +--ro wson-dwdm-channel-spacing?  identityref
    +--:(cwdm)
      +--ro wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:primary-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+--:(wson)
  +--ro (grid-type)?
  +--:(dwdm)
    | +--ro (single-or-super-channel)?
    |   +--:(single)
    |   | +--ro dwdm-n?  10-types:dwdm-n
    |   +--:(super)
    |   | +--ro subcarrier-dwdm-n*  10-types:dwdm-n

```

```

      +---:(cwdm)
        +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)
            +---ro subcarrier-dwdm-n*   10-types:dwdm-n
    +---:(cwdm)
      +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)
            +---ro subcarrier-dwdm-n*   10-types:dwdm-n
    +---:(cwdm)
      +---ro cwdm-n?                               10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:information-source-entry/tet:connectivity-matrices
  /tet:connectivity-matrix/tet:optimizations/tet:algorithm
  /tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
    +---:(dwdm)
      +---ro (single-or-super-channel)?
        +---:(single)
          | +---ro dwdm-n?                               10-types:dwdm-n
          +---:(super)

```

```

    |          +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |          +---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:information-source-entry/tet:connectivity-matrices
    /tet:connectivity-matrix/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
+---ro (grid-type)?
+---:(dwdm)
|   +---ro (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---ro dwdm-n?                10-types:dwdm-n
|   |   +---:(super)
|   |   +---ro subcarrier-dwdm-n*    10-types:dwdm-n
+---:(cwdm)
+---ro cwdm-n?                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-end/tet:te-label
    /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?    10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities/tet:label-restrictions
    /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---rw (l0-grid-type)?
+---:(dwdm)
|   +---rw wson-dwdm-channel-spacing?    identityref

```

```

      +---:(cwdm)
        +---rw wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          | +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:underlay
  /tet:backup-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          | +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n? 10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-exclude-objects
  /tet:route-object-exclude-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      +---rw (single-or-super-channel)?
        +---:(single)
          | +---rw dwdm-n? 10-types:dwdm-n
        +---:(super)
          | +---rw subcarrier-dwdm-n* 10-types:dwdm-n
    +---:(cwdm)

```

```

      +---rw cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:optimizations
  /tet:algorithm/tet:metric/tet:optimization-metric
  /tet:explicit-route-include-objects
  /tet:route-object-include-object/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
  +---:(dwdm)
  |   +---rw (single-or-super-channel)?
  |   |   +---:(single)
  |   |   |   +---rw dwdm-n?                        10-types:dwdm-n
  |   |   +---:(super)
  |   |   |   +---rw subcarrier-dwdm-n*            10-types:dwdm-n
  |   +---:(cwdm)
  |   +---rw cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities/tet:path-properties
  /tet:path-route-objects/tet:path-route-object/tet:type
  /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---ro (grid-type)?
  +---:(dwdm)
  |   +---ro (single-or-super-channel)?
  |   |   +---:(single)
  |   |   |   +---ro dwdm-n?                        10-types:dwdm-n
  |   |   +---:(super)
  |   |   |   +---ro subcarrier-dwdm-n*            10-types:dwdm-n
  |   +---:(cwdm)
  |   +---ro cwdm-n?                                10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:label-restrictions
  /tet:label-restriction/tet:label-start/tet:te-label
  /tet:technology:
+---:(wson)
  +---rw (grid-type)?
  +---:(dwdm)
  |   +---rw dwdm-n?    10-types:dwdm-n
  +---:(cwdm)
  |   +---rw cwdm-n?    10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities

```



```

        /tet:local-link-connectivity/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw dwdm-n?      10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?      10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:label-restrictions
  /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
  +---rw (l0-grid-type)?
    +---:(dwdm)
      | +---rw wson-dwdm-channel-spacing?  identityref
    +---:(cwdm)
      +---rw wson-cwdm-channel-spacing?  identityref
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay
  /tet:primary-path/tet:path-element/tet:type/tet:label
  /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw (single-or-super-channel)?
      |   +---:(single)
      |     | +---rw dwdm-n?      10-types:dwdm-n
      |     +---:(super)
      |       +---rw subcarrier-dwdm-n*  10-types:dwdm-n
    +---:(cwdm)
      +---rw cwdm-n?      10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
  /tet:tunnel-termination-point
  /tet:local-link-connectivities
  /tet:local-link-connectivity/tet:underlay/tet:backup-path
  /tet:path-element/tet:type/tet:label/tet:label-hop
  /tet:te-label/tet:technology:
+---:(wson)
  +---rw (grid-type)?
    +---:(dwdm)
      | +---rw (single-or-super-channel)?
      |   +---:(single)
      |     | +---rw dwdm-n?      10-types:dwdm-n

```

```

    |         +---:(super)
    |         |         +---rw subcarrier-dwdm-n*      10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-exclude-objects
    /tet:route-object-exclude-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |         +---rw (single-or-super-channel)?
    |         |         +---:(single)
    |         |         |         +---rw dwdm-n?      10-types:dwdm-n
    |         |         +---:(super)
    |         |         |         +---rw subcarrier-dwdm-n*  10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:optimizations
    /tet:algorithm/tet:metric/tet:optimization-metric
    /tet:explicit-route-include-objects
    /tet:route-object-include-object/tet:type/tet:label
    /tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |         +---rw (single-or-super-channel)?
    |         |         +---:(single)
    |         |         |         +---rw dwdm-n?      10-types:dwdm-n
    |         |         +---:(super)
    |         |         |         +---rw subcarrier-dwdm-n*  10-types:dwdm-n
    +---:(cwdm)
    |         +---rw cwdm-n?                          10-types:cwdm-n
augment /nw:networks/nw:network/nw:node/tet:te
    /tet:tunnel-termination-point
    /tet:local-link-connectivities
    /tet:local-link-connectivity/tet:path-properties
    /tet:path-route-objects/tet:path-route-object/tet:type
    /tet:label/tet:label-hop/tet:te-label/tet:technology:
+---:(wson)
    +---ro (grid-type)?

```

```

    +---:(dwdm)
    |   +---ro (single-or-super-channel)?
    |       +---:(single)
    |           |   +---ro dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---ro subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---ro cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:underlay/tet:primary-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:underlay/tet:backup-path
    /tet:path-element/tet:type/tet:label/tet:label-hop
    /tet:te-label/tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw (single-or-super-channel)?
    |       +---:(single)
    |           |   +---rw dwdm-n?           10-types:dwdm-n
    |       +---:(super)
    |           +---rw subcarrier-dwdm-n*    10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions
    /tet:label-restriction/tet:label-start/tet:te-label
    /tet:technology:
+---:(wson)
    +---rw (grid-type)?
    +---:(dwdm)
    |   +---rw dwdm-n?           10-types:dwdm-n
    +---:(cwdm)
    |   +---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
    /tet:te-link-attributes/tet:label-restrictions

```

```

        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?   10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---rw (l0-grid-type)?
+---:(dwdm)
|   +---rw wson-dwdm-channel-spacing?   identityref
+---:(cwdm)
+---rw wson-cwdm-channel-spacing?   identityref
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:information-source-entry/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(wson)
+---ro (grid-type)?
+---:(dwdm)
|   +---ro dwdm-n?   10-types:dwdm-n
+---:(cwdm)
+---ro cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:information-source-entry/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
+---ro (grid-type)?
+---:(dwdm)
|   +---ro dwdm-n?   10-types:dwdm-n
+---:(cwdm)
+---ro cwdm-n?   10-types:cwdm-n
augment /nw:networks/nw:network/nt:link/tet:te
        /tet:information-source-entry/tet:label-restrictions
        /tet:label-restriction/tet:label-step/tet:technology:
+---:(wson)
+---ro (l0-grid-type)?
+---:(dwdm)
|   +---ro wson-dwdm-channel-spacing?   identityref
+---:(cwdm)
+---ro wson-cwdm-channel-spacing?   identityref
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:underlay/tet:primary-path

```

```

        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?           10-types:dwdm-n
|   |   +---:(super)
|   |       +---rw subcarrier-dwdm-n* 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:underlay/tet:backup-path
        /tet:path-element/tet:type/tet:label/tet:label-hop
        /tet:te-label/tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw (single-or-super-channel)?
|   |   +---:(single)
|   |   |   +---rw dwdm-n?           10-types:dwdm-n
|   |   +---:(super)
|   |       +---rw subcarrier-dwdm-n* 10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?           10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-start/tet:te-label
        /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?       10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?          10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions
        /tet:label-restriction/tet:label-end/tet:te-label
        /tet:technology:
+---:(wson)
+---rw (grid-type)?
+---:(dwdm)
|   +---rw dwdm-n?       10-types:dwdm-n
+---:(cwdm)
+---rw cwdm-n?          10-types:cwdm-n
augment /nw:networks/tet:te/tet:templates/tet:link-template
        /tet:te-link-attributes/tet:label-restrictions

```

```

        /tet:label-restriction/tet:label-step/tet:technology:
+--:(wson)
  +--rw (l0-grid-type)?
    +--:(dwdm)
      |   +--rw wson-dwdm-channel-spacing?  identityref
    +--:(cwdm)
      |   +--rw wson-cwdm-channel-spacing?  identityref

```

### 3. The YANG Code for WSON topology

```

<CODE BEGINS> file "ietf-wson-topology@2020-10-16.yang"
module ietf-wson-topology {
  yang-version 1.1;
  namespace "urn:ietf:params:xml:ns:yang:ietf-wson-topology";
  prefix "wson";

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

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

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

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

  /* Note: The RFC Editor will replace XXXX with the number assigned
     to the RFC once draft-ietf-ccamp-layer0-types becomes an RFC.*/

  organization

```

```
"IETF CCAMP Working Group";

contact
  "WG Web: <http://tools.ietf.org/wg/ccamp/>
  WG List: <mailto:ccamp@ietf.org>

  Editor: Haomian Zheng
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          <aihuaguo.ietf@gmail.com>
  Editor: Victor Lopez
          <victor.lopezalvarez@telefonica.com>

  Editor: Daniel King
          <d.king@lancaster.ac.uk>";

description
  "This module provides a YANG data model for the routing and
  wavelength assignment (RWA) Traffic Engineering (TE)
  topology in wavelength switched optical networks (WSONs).
  The YANG model described in this document is a WSON
  technology-specific YANG model augmenting the generic TE
  topology module (ietf-te-topology) based on the information
  model developed in RFC 7446 and the two encoding documents
  RFC 7579 and RFC 7581.

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  as authors of the code. All rights reserved.

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  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).

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

revision 2020-10-16 {
  description
    "Initial Version";
  reference
    "RFC XXXX: A YANG Data Model for WSON (Wavelength Switched
```

```
    Optical Networks)";
    // RFC Ed.: replace XXXX with actual RFC number, update date
    // information and remove this note
}

/*
 * Data nodes
 */

augment "/nw:networks/nw:network/nw:network-types"
  + "/tet:te-topology" {
  description
    "Augment network types to define WSON topology type.";
  container wson-topology {
    presence
      "Its presence identifies the WSON topology type.";
    description
      "Introduce new network type for WSON topology.";
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te"
  + "/tet:te-node-attributes" {
  when "/nw:networks/nw:network/nw:network-types"
    + "/tet:te-topology/wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description "Augment TE node attributes.";
  container wson-node {
    presence "The TE node is a WSON node.";
    description "WSON node attributes";
    leaf is-reconfigurable-node {
      type boolean;
      default true;
      description
        "Indicates whether the WSON node is reconfigurable:
        - true: the node is reconfigurable, i.e.,
          it is representing a ROADM node;
        - false: the node is not reconfigurable, i.e.,
          it is representing a FOADM node.";
    }
  }
}

/*
 * Augment TE label range information
```



```

*/
augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range information for the TE node
    connectivity matrices.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:from/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range information for the source LTP
    of the connectivity matrix entry.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/tet:to/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../.../../.../../.../../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range information for the destination LTP
    of the connectivity matrix entry.";
uses l0-types:l0-label-range-info;
}

```

```
augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/"
  + "tet:connectivity-matrices/tet:label-restrictions/"
  + "tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the TE node
  connectivity matrices information source.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:from/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the source LTP
  of the connectivity matrix entry information source.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction" {
when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range information for the destination LTP
  of the connectivity matrix entry information source.";
uses l0-types:l0-label-range-info;
}
```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
  "Augmentation parameters apply only for networks with
  WSON topology type.";
}
description
  "Augment TE label range information for the TTP
  Local Link Connectivities.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
  "Augmentation parameters apply only for networks with
  WSON topology type.";
}
description
  "Augment TE label range information for the TTP
  Local Link Connectivity entry.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction" {
when "../..../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
  "Augmentation parameters apply only for networks with
  WSON topology type.";
}
description
  "Augment TE label range information for the TE link.";
uses l0-types:l0-label-range-info;
}

augment "/nw:networks/nw:network/nt:link/tet:te/"

```

```

        + "tet:information-source-entry/"
        + "tet:label-restrictions/tet:label-restriction" {
when "../.../.../.../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range information for the TE link
        information source.";
    uses l0-types:l0-label-range-info;
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction" {
    description
        "Augment TE label range information for the TE link template.";
    uses l0-types:l0-label-range-info;
}

/*
 * Augment TE label
 */

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range start for the TE node
        connectivity matrices";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:label-restrictions/"

```

```
+ "tet:label-restriction/tet:label-end/"
+ "tet:te-label/tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range end for the TE node
      connectivity matrices";
case wson {
uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:label-restrictions/"
+ "tet:label-restriction/tet:label-step/"
+ "tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
    "Augment TE label range step for the TE node
      connectivity matrices";
case wson {
uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:primary-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
when "../.../../...../nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
      WSON topology type.";
}
description
```

```

    "Augment TE label hop for the underlay primary path of the
      TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:underlay/tet:backup-path/tet:path-element/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path of the
      TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:te-node-attributes/tet:connectivity-matrices/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-exclude-objects/"
+ "tet:route-object-exclude-object/"
+ "tet:type/tet:label/tet:label-hop/"
+ "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects excluded
      by the path computation of the TE node connectivity
      matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

```

```

    }
  }

  augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/"
    + "tet:type/tet:label/tet:label-hop/"
    + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TE node connectivity
    matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:path-properties/tet:path-route-objects/"
  + "tet:path-route-object/tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
  when "../../../../../../../../../../../../../../../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label hop for the computed path route objects
    of the TE node connectivity matrices";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range start for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label range end for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:from/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology" {
when "../.../.../.../.../.../.../.../.../..."

```



```

    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label range step for the source LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:to/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label range start for the destination LTP
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/tet:to/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/"
    + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
}

```

```

    description
      "Augment TE label range end for the destination LTP
      of the connectivity matrix entry.";
    case wson {
      uses 10-types:wson-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:to/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/"
  + "tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry.";
case wson {
  uses 10-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../"
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the connectivity matrix entry.";
case wson {
  uses 10-types:wson-label-hop;
}
}

```

```

}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:backup-path/tet:path-element/"
  + "tet:type/tet:label/tet:label-hop/"
  + "tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the connectivity matrix entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"
  + "tet:algorithm/tet:metric/tet:optimization-metric/"
  + "tet:explicit-route-exclude-objects/"
  + "tet:route-object-exclude-object/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the explicit route objects excluded
  by the path computation of the connectivity matrix entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:te-node-attributes/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/tet:optimizations/"

```

```

    + "tet:algorithm/tet:metric/tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:te-node-attributes/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the connectivity matrix entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range start for the TE node connectivity
        matrices information source.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range end for the TE node connectivity
        matrices information source.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/"
    + "tet:connectivity-matrices/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-step/tet:technology" {
    when "../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range step for the TE node connectivity
        matrices information source.";
    case wson {

```

```

    uses l0-types:wson-label-step;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay primary path
     of the TE node connectivity matrices of the information
     source entry.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
  when "../.../.../.../.../.../.../.../.../"
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
       WSON topology type.";
  }
  description
    "Augment TE label hop for the underlay backup path
     of the TE node connectivity matrices of the information
     source entry.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```

```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TE node connectivity matrices
    information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TE node connectivity matrices
    information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."

```

```

    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label hop for the computed path route objects
    of the TE node connectivity matrices information source.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:from/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description
    "Augment TE label range start for the source LTP
    of the connectivity matrix entry information source.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:from/tet:label-restrictions/"
    + "tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
    }
description

```



```

    "Augment TE label range end for the source LTP
      of the connectivity matrix entry information source.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:from/tet:label-restrictions/"
+ "tet:label-restriction/"
+ "tet:label-step/tet:technology" {
  when "../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label range step for the source LTP
      of the connectivity matrix entry information source.";
  case wson {
    uses l0-types:wson-label-step;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:to/tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../../../../../"
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
        WSON topology type.";
  }
  description
    "Augment TE label range start for the destination LTP
      of the connectivity matrix entry information source.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range end for the destination LTP
  of the connectivity matrix entry information source.";
case wson {
  uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:to/tet:label-restrictions/tet:label-restriction/"
  + "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label range step for the destination LTP
  of the connectivity matrix entry information source.";
case wson {
  uses l0-types:wson-label-step;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:information-source-entry/tet:connectivity-matrices/"
  + "tet:connectivity-matrix/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the connectivity matrix entry information source.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the connectivity matrix entry information source.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:information-source-entry/tet:connectivity-matrices/"
    + "tet:connectivity-matrix/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description

```

```

    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the connectivity matrix entry
    information source.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the explicit route objects included
  by the path computation of the connectivity matrix entry
  information source.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:information-source-entry/tet:connectivity-matrices/"
+ "tet:connectivity-matrix/"
+ "tet:path-properties/tet:path-route-objects/"
+ "tet:path-route-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the computed path route objects
  of the connectivity matrix entry information source.";

```

```

    case wson {
      uses 10-types:wson-label-hop;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-start/"
  + "tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../..."
      + "nw:network-types/tet:te-topology/"
      + "wson:wson-topology" {
        description
          "Augmentation parameters apply only for networks with
           WSON topology type.";
      }
    description
      "Augment TE label range start for the TTP
       Local Link Connectivities.";
    case wson {
      uses 10-types:wson-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:label-restrictions/tet:label-restriction/"
  + "tet:label-end/"
  + "tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../..."
      + "nw:network-types/tet:te-topology/"
      + "wson:wson-topology" {
        description
          "Augmentation parameters apply only for networks with
           WSON topology type.";
      }
    description
      "Augment TE label range end for the TTP
       Local Link Connectivities.";
    case wson {
      uses 10-types:wson-label-start-end;
    }
  }

augment "/nw:networks/nw:network/nw:node/tet:te/"

```

```

    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/"
    + "tet:technology"{
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range step for the TTP
        Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-step;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay primary path
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {

```

```

        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the underlay backup path
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-exclude-objects/"
+ "tet:route-object-exclude-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivities.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:optimizations/tet:algorithm/tet:metric/"
+ "tet:optimization-metric/"
+ "tet:explicit-route-include-objects/"
+ "tet:route-object-include-object/tet:type/"
+ "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description

```

```

        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label hop for the explicit route objects included
        by the path computation of the TTP Local Link
        Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label hop for the computed path route objects
        of the TTP Local Link Connectivities.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../.../.../.../.../.../.../.../..."
        + "nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range start for the TTP

```



```

        Local Link Connectivity entry.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range end for the TTP
    Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-start-end;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
+ "tet:tunnel-termination-point/"
+ "tet:local-link-connectivities/"
+ "tet:local-link-connectivity/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
when "../.../.../.../.../.../.../..."
+ "nw:network-types/tet:te-topology/"
+ "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
}
description
    "Augment TE label range step for the TTP
    Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-step;
}
}

```

```

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay primary path
  of the TTP Local Link Connectivity entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
  + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
  + "nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
  description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
  "Augment TE label hop for the underlay backup path
  of the TTP Local Link Connectivity entry.";
case wson {
  uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
  + "tet:tunnel-termination-point/"
  + "tet:local-link-connectivities/"
  + "tet:local-link-connectivity/"
  + "tet:optimizations/tet:algorithm/tet:metric/"
  + "tet:optimization-metric/"

```

```

    + "tet:explicit-route-exclude-objects/"
    + "tet:route-object-exclude-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects excluded
    by the path computation of the TTP Local Link
    Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nw:node/tet:te/"
    + "tet:tunnel-termination-point/"
    + "tet:local-link-connectivities/"
    + "tet:local-link-connectivity/"
    + "tet:optimizations/tet:algorithm/tet:metric/"
    + "tet:optimization-metric/"
    + "tet:explicit-route-include-objects/"
    + "tet:route-object-include-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the explicit route objects included
    by the path computation of the TTP Local Link
    Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}

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

```

```

    + "tet:path-properties/tet:path-route-objects/"
    + "tet:path-route-object/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the computed path route objects
    of the TTP Local Link Connectivity entry.";
case wson {
    uses l0-types:wson-label-hop;
}
}
augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description
    "Augment TE label hop for the underlay primary path
    of the TE link.";
case wson {
    uses l0-types:wson-label-hop;
}
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
when "../.../.../.../.../.../.../..."
    + "nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
description
    "Augmentation parameters apply only for networks with
    WSON topology type.";
}
description

```

```

    "Augment TE label hop for the underlay backup path
    of the TE link.";
  case wson {
    uses l0-types:wson-label-hop;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-start/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label range start for the TE link.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-end/tet:te-label/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description
      "Augmentation parameters apply only for networks with
      WSON topology type.";
  }
  description
    "Augment TE label range end for the TE link.";
  case wson {
    uses l0-types:wson-label-start-end;
  }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
+ "tet:te-link-attributes/"
+ "tet:label-restrictions/tet:label-restriction/"
+ "tet:label-step/tet:technology" {
  when "../../../../../../../nw:network-types/tet:te-topology/"
  + "wson:wson-topology" {
    description

```

```

        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range step for the TE link.";
    case wson {
        uses 10-types:wson-label-step;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    when "../..//../..//../..//nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range start for the TE link
        information source.";
    case wson {
        uses 10-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-end/tet:te-label/tet:technology" {
    when "../..//../..//../..//nw:network-types/tet:te-topology/"
        + "wson:wson-topology" {
        description
            "Augmentation parameters apply only for networks with
            WSON topology type.";
    }
    description
        "Augment TE label range end for the TE link
        information source.";
    case wson {
        uses 10-types:wson-label-start-end;
    }
}

augment "/nw:networks/nw:network/nt:link/tet:te/"
    + "tet:information-source-entry/"

```

```

    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-step/tet:technology" {
when "../.../.../.../.../nw:network-types/tet:te-topology/"
    + "wson:wson-topology" {
    description
        "Augmentation parameters apply only for networks with
        WSON topology type.";
    }
    description
        "Augment TE label range step for the TE link
        information source.";
    case wson {
        uses l0-types:wson-label-step;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:underlay/tet:primary-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    description
        "Augment TE label hop for the underlay primary path
        of the TE link template.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:underlay/tet:backup-path/tet:path-element/tet:type/"
    + "tet:label/tet:label-hop/tet:te-label/tet:technology" {
    description
        "Augment TE label hop for the underlay backup path
        of the TE link template.";
    case wson {
        uses l0-types:wson-label-hop;
    }
}

augment "/nw:networks/tet:te/tet:templates/"
    + "tet:link-template/tet:te-link-attributes/"
    + "tet:label-restrictions/tet:label-restriction/"
    + "tet:label-start/tet:te-label/tet:technology" {
    description
        "Augment TE label range start for the TE link template.";
    case wson {
        uses l0-types:wson-label-start-end;
    }
}

```

```
    }  
  }  
  
  augment "/nw:networks/tet:te/tet:templates/"  
    + "tet:link-template/tet:te-link-attributes/"  
    + "tet:label-restrictions/tet:label-restriction/"  
    + "tet:label-end/tet:te-label/tet:technology" {  
    description  
      "Augment TE label range end for the TE link template.";  
    case wson {  
      uses l0-types:wson-label-start-end;  
    }  
  }  
  
  augment "/nw:networks/tet:te/tet:templates/"  
    + "tet:link-template/tet:te-link-attributes/"  
    + "tet:label-restrictions/tet:label-restriction/"  
    + "tet:label-step/tet:technology" {  
    description  
      "Augment TE label range step for the TE link template.";  
    case wson {  
      uses l0-types:wson-label-step;  
    }  
  }  
}  
  
<CODE ENDS>
```

#### 4. Security Considerations

The YANG module specified in this document defines a schema for data that is designed to be accessed via network management protocols such as NETCONF [RFC6241] or RESTCONF [RFC8040]. The lowest NETCONF layer is the secure transport layer, and the mandatory-to-implement secure transport is Secure Shell (SSH) [RFC6242]. The lowest RESTCONF layer is HTTPS, and the mandatory-to-implement secure transport is TLS [RFC8446].

The NETCONF Protocol over Secure Shell (SSH) [RFC6242] describes a method for invoking and running NETCONF within a Secure Shell (SSH) session as an SSH subsystem. The NETCONF access control model [RFC8341] provides the means to restrict access for particular NETCONF or RESTCONF users to a preconfigured subset of all available NETCONF or RESTCONF protocol operations and content.

There are a number of data nodes defined in this YANG module that are writable/creatable/deletable (i.e., config true, which is the



default). These data nodes may be considered sensitive or vulnerable in some network environments. Write operations (e.g., edit-config) to these data nodes without proper protection can have a negative effect on network operations. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

Some of the readable data nodes in this YANG module may be considered sensitive or vulnerable in some network environments. It is thus important to control read access (e.g., via get, get-config, or notification) to these data nodes. Considerations in Section 8 of [RFC8795] are also applicable to their subtrees in the module defined in this document.

## 5. IANA Considerations

It is proposed to IANA to assign new URIs from the "IETF XML Registry" [RFC3688] as follows:

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

This document registers a YANG module in the YANG Module Names registry [RFC7950] and [RFC6020].

name: ietf-wson-topology  
namespace: urn:ietf:params:xml:ns:yang:ietf-wson-topology  
prefix: wson  
reference: RFC XXXX

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GMPLS Routing and Signaling Framework for Flexible Ethernet (FlexE)  
draft-izh-ccamp-flex-e-fwk-03

Abstract

As different from earlier Ethernet data planes FlexE allows for decoupling of the Ethernet Physical layer (PHY) and Media Access Control layer (MAC) rates.

Study Group 15 (SG15) of the ITU-T has endorsed the FlexE Implementation Agreement from Optical Internetworking Forum (OIF) and included it, by reference, in some of their Recommendations.

This document specifies the use cases of FlexE technology, GMPLS control plane requirements, framework, and architecture.

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## 1. Introduction

Ethernet MAC rates were until recently constrained to match the rates of the Ethernet PHY(s). Work within the OIF allows MAC rates to be different from PHY rates. An OIF implementation agreement [OIFFLEXE1] allows for complete decoupling of the MAC and PHY rates.

SG15 in ITU-T has endorsed the OIF FlexE data plane and parts of [G.872], [G.709], [G.798] and [G.8021] depends on or are based on the FlexE data plane.

This includes support for

- a. MAC rates which are greater than the rate of a single PHY; multiple PHYs are bonded to achieve this
- b. MAC rates which are less than the rate of a PHY (sub-rate)
- c. support of multiple FlexE CLients carried over a single PHY, or over a collection of bonded PHYs.

The capabilities supported by the first version of the FlexE data plane are:

- a. Support a large rate Ethernet MAC over bonded Ethernet PHYs, e.g. supporting a 200G MAC over 2 bonded 100GBASE-R PHY(s)
- b. Support a sub-rate Ethernet MAC over a single Ethernet PHY, e.g. supporting a 50G MAC over a 100GBASE-R PHY
- c. Support a collection of flexible Ethernet clients over a single Ethernet PHY, e.g. supporting two MACs with the rates 25G, and one with rate 50G over a single 100GBASE-R PHY
- d. Support a sub-rate Ethernet MAC over bonded PHYs, e.g. supporting a 150G Ethernet client over 2 bonded 100GBASE-R PHY(s)
- e. Support a collection of Ethernet MAC clients over bonded Ethernet PHYs, e.g. supporting a 50G, and 150G MAC over 2 bonded Ethernet PHY(s)

Networks which support FlexE Ethernet interfaces include a basic building block, this is true also when the interfaces are bonded. This building block consists of two FlexE Shim functions, located at opposite ends of a link, and the logical point to point links that carry the Ethernet PHY signals between the two FlexE Shim Functions.

These logical point-to-point PHY links may be realized in a variety of ways:

- a. direct point-to-point links with no intervening transport network.
- b. Ethernet PHY(s) may be transparently transported via an Optical Transport Network (OTN), as defined by ITU-T in [G.709] and [G.798]. The OTN set of client mappings has been extended to support the use cases identified in the OIF FlexE implementation agreement.

This document examines the use cases that arise when the logical links between FlexE capable devices are

- (a) point-to-point links without any intervening network
- (b) realized via Optical transport networks.

This draft considers the variants in which the two peer FlexE devices are both customer-edge devices, or when one is a customer-edge and the other is provider edge devices. This list of use cases will help identify the Control Plane (i.e. Routing and Signalling) extensions that may be required.

### 1.1. Requirements Language

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

## 2. Terminology

- a. AC (Attachment Circuit) - the connectivity between a client/customer network and a provider network.
- b. CE (Customer Edge) - the group of functions that support the termination/origination of data received from or sent to the network
- c. Crunching: The process of compressing an Ethernet PHY signal by eliminating the unavailable FlexE calendar slots at the ingress to the transport network; these discarded unavailable FlexE calendar slots are re-inserted (with fixed content) at the transport network egress.
- d. Ethernet PHY: an entity representing Physical Coding Sublayer (PCS), Physical Media Attachment (PMA), and Physical Media Dependent (PMD) layers.



- e. FlexE Calendar: The total capacity of a FlexE Group is represented as a collection of slots which have a granularity of 5G. The calendar for a FlexE Group composed of  $n$  100G PHYs is represented as an array of  $20n$  slots (each representing 5G of bandwidth). This calendar is partitioned into sub-calendars, with 20 slots per 100G PHY. Each FlexE client is mapped into one or more calendar slots (based on the bandwidth the FlexE client flow will need).

Note this description of the FlexE Calendar is based on the first version of FlexE, for future version changes in the granularity and PHY rates are under study.

- f. FlexE Client: An Ethernet flow based on a MAC data rate that may or may not correspond to any Ethernet PHY rate.
- g. FlexE Group: A FlexE Group is composed of from 1 to  $n$  Ethernet PHYs. In the first version of FlexE each PHY is identified by a number in the range {1-254}.
- h. FlexE Interface: A logical interface that is composed of from 1 to  $n$  Ethernet interfaces.
- i. FlexE Link: A logical link that connects two FlexE interfaces residing in two adjacent nodes.
- j. FlexE Shim: the layer that maps or demaps the FlexE client flows carried over a x Group.
- k. FlexE Sub-Interface: A channelized logical sub-interface that is allocated specific slots from a FlexE interface, the number of slots depend on the rate of the FlexE client flow that will be transmitted through this sub-interface.
- l. FlexE Sub-Link: A logical link that connects two FlexE sub-interfaces that residing in two adjacent nodes.
- m. LMP: Link Management Protocol
- n. LSP: Label Switched Path
- o. OTN: Optical Transport Network
- p. PW: Pseudowire
- q. SG15: ITU-T Study Group 15 (Transport, Access and Home).
- r. TE: Traffic Engineering

s. TED: Traffic Engineering Database

t. TN: Transport Network

### 3. Use Cases

This section describes 5 major use cases as a background to the requirements in Section 4. The use cases are Back-to-Back FlexE, FlexE Unaware transport, FlexE Aware transport, FlexE Termination in Transport, and FlexE client BW Resizing.

FlexE aware routers and OTN equipment have a functionality (FlexE Shim) that handles FlexE connectivity and termination. In the first generation of FlexE the PHYs are 100 Gbit/s and are structured into 5 Gbit/s slots. In the simplest case a FlexE Group and a PHY are identical, PHYs can also be combined to form larger FlexE Groups.

FlexE MACs can be built through combining one or more 5 Gbits slots. The slots does not need to come from the same PHY, but need to be part of the same FlexE Group

#### 3.1. Back-to-Back FlexE

This section describes a FlexE scenario in which routers are interconnected back-to-back through FlexE Groups without an intermediate transport network, see Figure 1 below.

The scenarios describe in Section 3.1 assumes the first generation of FlexE.

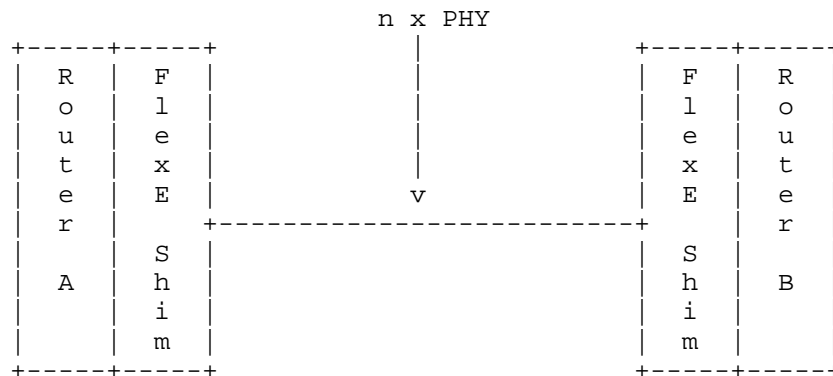


Figure 1: FlexE back-to-back Use Case

In this case we assume that we want to establish an  $x$  Gbit/s FlexE LSP between router A and B, using  $y$  5 Gbit/s slots from  $z$  PHYs.

- o For the first version of FlexE,  $x$  can be 10, 40, or a multiple of 25 Gbit/s;
- o  $y$  is equal to  $x/5$ ;
- o  $z$  can be any figure between 1 and  $n$ ;

The GMPLS peers are the FlexE aware routers (routers A and B), and GMPLS signaling and exchange of traffic engineering information takes place between the peers.

To set up this FlexE LSP by an GMPLS control plane the OSPF-TE [RFC4203] and ISIS-TE [RFC5305] needs to be extended to keep FlexE traffic engineering information, e.g. the number of used and available of 5 Gbit/s slots between a pair of routers. RSVP-TE needs to be extended to set up right size LSP between the pair of routers. The LSP creates a set of FlexE sub-interfaces on the routers and concatenate them (by means of MPLS labels) to form an end-2-end path.

The action to establish the LSP, involves coordinating a number of 5 Gbit/s slots from the FlexE group to create the MAC layer and the FlexE sub-interface.

### 3.2. Unaware Transport

In this use case the routers that originates and terminates the FlexE PHYs and MACs are interconnected by an OTN network. The OTN network is unaware what type of traffic is carried over the OTN network.

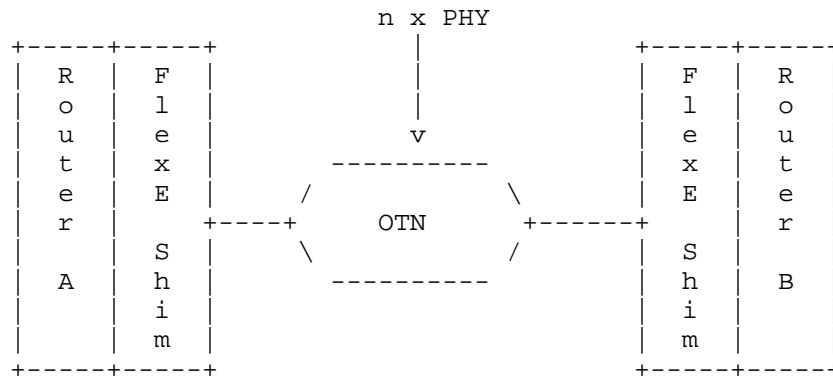


Figure 2: FlexE Unaware Transport

This use case is from a GMPLS control plane point of view identical to Figure 1.

The GMPLS peers are the FlexE aware routers, and GMPLS signaling and exchange of traffic engineering information takes place between the peers, e.g. router A and B. The OTN is FlexE unaware and is not involved in the exchange of traffic engineering information and signaling.

### 3.3. Aware Transport

In this use case the OTN edge nodes (PE) and the routers (CE) that are connected to the OTN network are aware of that the connections carry FlexE traffic. The Attachment Circuit (AC) carries the full PHY bandwidth, while the OTN FlexE Aware PEs has a function called "crunching" that removes unavailable slots.

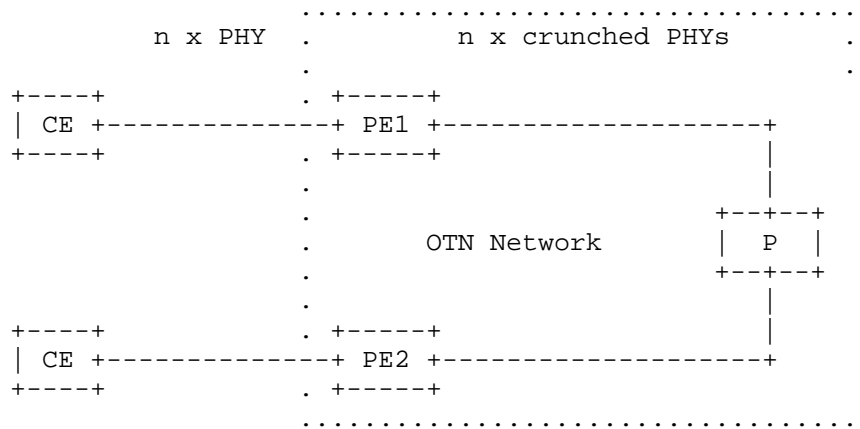


Figure 3: FlexE Aware Transport

Between PE1 and PE2 there is a mechanism ("crunching") that can remove PHY slots that are not carrying traffic, this mechanism will decrease the bandwidth necessary to carry by the OTN network.

The mapping between PHY(s) and MAC are called "calendar", the calendar indicates which slots that carry traffic.

The active calendar is managed by the data plane, and will be changed to match the intended calendar to complete the bandwidth resizing.

Apart from the requirements listed in Section 4 the GMPLS control plane may be used to distribute traffic engineering and control information, e.g. distributing the intended calendar, when bandwidth resizing is requested.

### 3.4. FleE Termination in Transport

The figure need to be added.

This use case does not generate any new requirements for a GMPLS control plane as compared to Section 3.1, Section 3.2, and Section 3.3.

## 3.5. FlexE Client BW Resizing

The table below show where FlexE resixing is supported.

\*\*\*

end-points	use case	TN Function	Resizing supported
CE/CE	Sec 3.2	FlexE unaware TN	Yes, by CEs. The OTN pipes are configured for the maximum number of calendar slots across each PHY in the FlexE group, no resizing required in the OTN Layer.
CE/CE	Sec 3.3	FlexE aware TN	Limited support. Supported at the endpoints only if the set of available/unavailable calendar slots is constant. Not supported otherwise, see notes at the end of Sec 3.2.
CE/PE	Sec 3.4	FlexE termination within TN	No. Resizing not supported due to lack of a general hitless resizing mechanism in OTN,
CE/CE	Sec 3.1	No TN	Yes, by CEs. The resizing of FlexE connections that transit multiple FlexE Groups (as in Figure 6) can be accomplished by coordinating the resize operations across each of the hops.

\*\*\*

Figure 4: FlexE Client Resizing

This use case does not generate any new requirements for a GMPLS control plane as compared to Section 3.1, Section 3.2, and Section 3.3.

#### 4. Requirements

This section summarizes the requirements for FlexE Group and FlexE client signaling and routing. The requirements are derived from the usecases described in Section 3 of this document. Data plane requirements (and/or solutions) (e.g. crunching of tributary slots, adding unavailable tributary slots etc.) are not explicitly mentioned in the following text. Given that the control plane sets up circuits that transport client streams, there are no implications for the control plane in matters of delay, jitter tolerance etc. The requirements listed in this section will be used to identify the Control Plane (i.e. Routing and Signaling) extensions that will be required to support FlexE services in an OTN.

- Req-1 The solution SHALL support the creation of a FlexE Group, consisting of one or more (i.e., in the 1 to 254 range) 100GE Ethernet PHY(s).

There are several alternatives that can meet this requirement, e.g. routing and signaling protocols, or a centralized controller/management system with network access to the FlexE mux/demux at each FlexE Group termination point.

- Req-2 The solution SHOULD be able to verify that the collection of Ethernet PHY(s) included in a FlexE Group have the same characteristics (e.g. number of PHYs, rate of PHYs, etc.) at the peer FlexE shims.
- Req-3 The solution SHALL support the ability to delete a FlexE Group.
- Req-4 The solution SHALL support the ability to administratively lock/unlock a FlexE Group.
- Req-5 It SHALL be possible to add/remove PHY(s) to/from an operational FlexE group while the group has been administratively locked.
- [Note: Since the addition/removal of Ethernet PHY(s) is done only when the group has been locked, this dataplane operation of the FlexE Group ceases until it is placed in an unlocked state.]
- Req-6 The solution SHALL support the ability to advertise (and discover) the information about FlexE capable nodes, and the FlexE interfaces/sub-interfaces they are supporting.

- Req-7 It SHALL be possible to assign the transport network treatment for a FlexE Group to one the following choices:
- (a) FlexE unaware transport
  - (b) FlexE aware transport
  - (c) FlexE termination in Transport.
- Req-8 For the FlexE unaware case, each of the Ethernet PHY(s) in the FlexE group SHALL be mapped independently to the appropriately sized ODU container (as per [G.709], and switched across the transport network [OIFFLEXE1]. The control plane SHALL be capable of co-routing the ODU signals that are transporting the member PHY(s) between the two FlexE Shim functions.
- Note: Insert applicable references to ITU, OIF spec for hard skew tolerances]
- Req-9 In the FlexE aware mode, the OTN SHALL crunch the PHY(s), and map them to one or more ODUFlex connections as per [G.709].
- When two or more ODUFlex connections are used to transport the collection of FlexE PHY(s) in a FlexE Group, the system SHALL support the ability to constrain the routes for these ODUFlex connections (e.g. co-route them) so that the end-to-end skew is kept to a minimum (and within the range supported by the FlexE Shims).
- Req-10 The system SHALL allow the addition (or removal) of one or more FlexE clients against the FlexE Group which is being terminated. The addition (or removal) of a FlexE client flow SHALL NOT affect the services for the other FlexE client signals.
- Req-11 The system SHALL allow the FlexE client signals to flexibly span the set of Ethernet PHY(s) which comprise the FlexE Group. In other words, it SHALL be possible to distribute any FlexE client flow over an arbitrary combination of calendar slots (whose total capacity matches the client bitrate) chosen from a subset of the PHY(s).
- Req-12 When the FlexE Group is terminated on the Transport edge node, this node SHOULD be capable of resizing one or more FlexE client flow (using the "A/B" calendar signaling defined by OIF) (see Figure 4). It is acceptable that this resizing



is not hitless, and the client signal incurs a glitch during the resizing operation.

There is no requirement for the OTN network to support the hitless resizing of the ODUFlex connection which is transporting the FlexE client signal.

Req-13 The solution SHALL support FlexE client flow resizing without affecting any existing FlexE clients within the same FlexE Group.

Req-14 The solution SHALL support establishment of single- and multihop end-2-end LSPs.

## 5. Framework and Architecture

This section discusses FlexE framework and architecture. Framework is taken to mean how FlexE interoperates with other parts of the data communication system. Architecture is taken to mean how functional groups and elements within FlexE work together to deliver the expected FlexE services. Framework is taken to mean how FlexE interacts with its environment.

### 5.1. FlexE Framework

The service offered by Flexible Ethernet is a transport service very similar (or even identical) to the service offered by Ethernet.

There are two major additions supported by FlexE:

- o FlexE is intended to support high bandwidth and FlexE can offer granular bandwidth from 5Gbits/s and a bandwidth as high as the FlexE Group allows.
- o As FlexE groups and clients are set up as a configuration activity, by a centralized controller or by a GMPLS control plane the service is connection oriented.

#### 5.1.1. FlexE Reference Model

The figure below gives a simplified FlexE reference model.

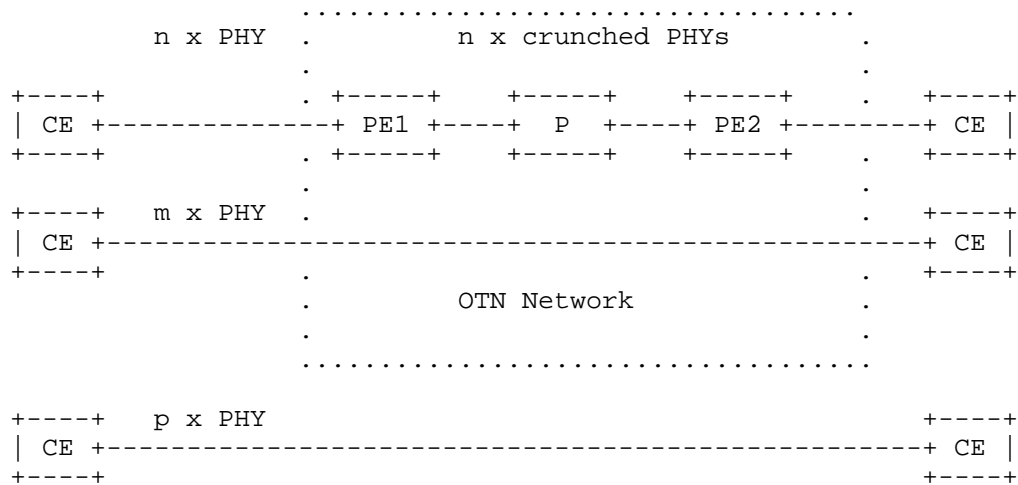


Figure 5: FlexE Reference Model

### 5.1.2. FlexE Services

The services offered by Flexible Ethernet are essentially the same as for traditional Ethernet, connection less Ethernet transport. However, when the relationship between the PHY and MAC layer are set up by a GMPLS control plane there is a strong connection oriented aspect.

## 5.2. FlexE Architecture

### 5.2.1. Architecture Components

Editors Note (to be removed): this section needs some serious polishing and also add the missing text.

This section discusses the different parts of FlexE signaling and routing and how these parts interoperate.

The FlexE routing mechanism is used to provide resource available information for set up of FlexE LSP, like Ethernet PHYs' information, partial-rate support information. Based on the resource available information advertised by routing protocol, an end-to-end FlexE connection is computed, and then the signaling protocol is used to set up the end-to-end connection.

FlexE signaling mechanism is used to set up a FlexE LSPs.

#### 5.2.2. FlexE Layer Model

The FlexE layer model is similar Ethernet model, the Ethernet PHY layer corresponds to the "FlexE Group", and the MAC layer corresponds to the "FlexE Client".

As different from earlier Ethernet the combination of FlexE Group and Client allows for a huge freedom when it comes to define the bandwidth of an Ethernet connectivity.

##### 5.2.2.1. FlexE Group structure

The FlexE Group might be supported by virtually any transport network, including the Ethernet PHY. While the Ethernet PHY offers a fixed bandwidth the FlexE Group has been structured into 5 Gbit/s slots. This means that the FlexE Group can support FlexE clients of a variety of bandwidths.

The first version is defined for 20 slots of 5 Gbit/s over a 100 Gbit/s PHY. The 100 Gbit/s PHYs can be bonded to give higher bandwidth.

##### 5.2.2.2. FlexE Client mapping

A FlexE client is an Ethernet flow based on a MAC data rate that may or may not correspond to any Ethernet PHY rate. The FlexE Shim is the layer that maps or demaps the FlexE client flows carried over a FlexE group. As defined in [OIFFLEXE1], MAC rates of 10, 40, and any multiple of 25 Gbit/s are supported. This means that if there is a 100 Gbit/s FlexE Group between A and B, a FlexE client of 10, 25, 40, 50, 75 and 100 Gbit/s can be created.

However, by bonding, for example 5 PHYs of 100 Gbit/s to a single FlexE group, FlexE clients of 500 Gbit/s can be supported.

## 6. Control Plane

This section discusses the procedures and extensions needed to the GMPLS Control Plane to establish FlexE LSPs.

There are several ways to establish FlexE groups, allocate slots for FlexE clients, and set up single-hop and multi-hop end to end FlexE LSPs. A configuration tool, a centralized controller or the GMPLS control plane can all be used.

To create the FlexE GMPLS control plane extensions to the following protocols may be needed:

- o "RSVP-TE: Extensions to RSVP for LSP Tunnels" (RSVP-TE) [RFC3209]
- o "Link Management Protocol" (LMP) [RFC4204]
- o "Path Computation Element (PCE) Communication Protocol" (PCEP) [RFC5440]
- o IS-IS Extensions for Traffic Engineering (ISIS-TE) [RFC5305]
- o "OSPF Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)" (OSPF-TE) [RFC4203]
- o "North-Bound Distribution of Link-State and Traffic Engineering (TE) Information Using BGP" (BGP-LS) [RFC7752]

A FlexE control plane YANG model will also be needed.

Section 6.2 and Section 6.1 discusses the role of the GMPLS control plane when primarily setting up multi-hop LSPs.

When discussing the signaling and routing procedures and information we assume that the the FlexE group has been established prior to executing the procedures needed to establish a FlexE LSP. Technically it is possible to establish FlexE group, allocate FlexE client slots and FlexE LSP with a single exchange of GMPLS signaling messages.

#### 6.1. GMPLS Routing

To establish a FlexE LSP the Traffic Engineering (TE) information is the most critical information, e.g. resource utilisation on interfaces and link, including the availability of slots on the FlexE groups. The GMPLS routing protocols need to be extended to handle this information. The Traffic Engineering Database (TED) will keep an updated version of this information.

The FlexE capable nodes will be identified by IP-addresses, and the routing and traffic engineering information will be flooded to all nodes within the routing domain using TCP/IP.

When a FlexE LSP is about to be set up, e.g. R1 - R2 - R3 in Figure 6 the information in the TED is used to verify that resources are available. When it is confirmed that the FlexE LSP is established the TED is updated, marking the resources used for the new LSP as used. Similarly when a LSP is taken down the resources are marked as free.

## 6.2. GMPLS Signaling

In Figure 6 node R1 - R3 and R3 - R4, and R2 - R4 are connected by 100 Gbit/s FlexE groups. R2 - R4 are connected by 2 FlexE groups each 100 Gbit/s. In this example we will go through the procedures to set up two FlexE LSPs, the first (40 Gbit/s) R1 - R3 - R4, and the second (80 Gbit/s) R2 - R3 - R4.

The slots of the FlexE group between two nodes is controlled by the upstream node, while the assignment of a label for an LSP is controlled by the downstream node.

In Figure 6 the four nodes may be interconnected by the FlexE back-to-back or the Flex aware.

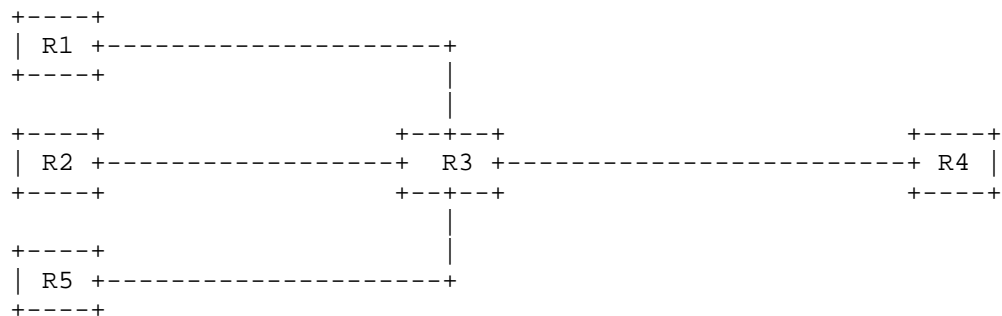


Figure 6: FlexE LSP Example

When an LSP is set up (e.g. R1 - R3 - R4) the following signaling steps takes place:

1. Node R1 identify the resources needed for the LSP, in this case we assume that a 40 Gbit/s LSP will be set up.
2. Node R1 identifies the next hop, in this case node R3.
3. Node R1 identifies the the slots to be used, we assume that slot 1, 3, 5, 7, 9, 11, 13 and 15 will be used. These slots will carry a FlexE client flow between R1 and R3.

4. Node R1 informs node R3 about the intention to set up the 40 Gbit/s LSP and allocation of slots for the FlexE client.
5. When R3 receives the message from R1 it verifies that the resources that R1 requests are available on the sub-link between R1 and R3. If they are R3 will send a message to R4 requesting a 20 Gbit/s FlexE LSP to be set up using for example slots 2, 4, 6, 8, 10 12, 14, and 16.
6. R4 verifies the availability of the resources, and if they are, R4 will also identify that it is the termination point of the intended LSP.
7. Being the termination point R4 will assign a label for the FlexE LSP. The label has the same format as MPLS Label specified in RFC 3032 [RFC3032].
8. Node R4 responds to the message requesting the set up of the LSP, by a message indicating that the requested slots are accepted used and the MPLS Label that shall be used.
9. When node R3 gets the response from R4, it responds to R1 indicating that the requested slots are accepted and the MPLS label to be used.
10. Once R1 gets the response from R3 the LSP is ready to carry traffic.

When the second LSP of 80 Gbit/s is set up (R2 - R3 - R4) is set up, the procedures are the same, the only difference is that between R3 and R4 the second LSP needs to be allocated to the second FlexE group between R3 and R4, since there is not enough bandwidth available on the FlexE Group where the first LSP were allocated.

It should also be noted that if we want to set up a third 80 Gbit/s LSP R5 - R3 - R4, this set up will fail. The reason is that even though the total free bandwidth between R3 and R4 is 80 Gbit/s, neither of the existing FlexE Groups has enough bandwidth to support an 80 Gbit/s LSP. Bonding of FlexE Groups that carry traffic is not possible.

It would be a good strategy for an operator to define a 200 Gbit/s FlexE group from the start if it is anticipated that there might be situations where some FlexE client flows will use slots from both PHYs.

### 6.3. FlexE Packet Label Switching Data Plane

This section discusses how the FlexE LSP data plane works. In general it can be said that the interface offered by the FlexE Shim and the FlexE client is equivalent to the interface offered by the Ethernet MAC.

Figure 7 below illustrates the FlexE packet switching data plane procedures.

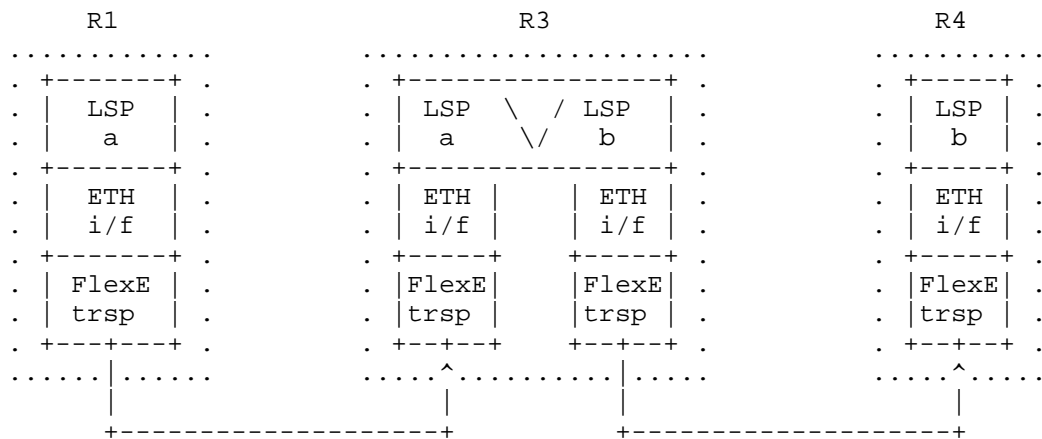


Figure 7: FlexE LSP Data Plane

Note to reviewers: I'm not certain about the terminology for this figure suggestions would be appreciated.

FlexE packet switching data plane processes packets like this:

- o The LSP encapsulating and forwarding function in node R1 receives a packet that needs to be encapsulated in an MPLS packet with the label "a". The label "a" is used to figure out with FlexE emulated Ethernet interfaces the label encapsulated packet needs to be forwarded over.
- o The Ethernet interfaces, by means of FlexE transport, forwards the packet to node R3. Node R3 swaps the label "a" to label "b" and uses "b" to decide over which interface to send the packet.
- o Node R3 forwards the packet to node R, which terminates the LSP.

Sending MPLS encapsulated packets over a FlexE sub-interface is similar to send them over an Ethernet 802.1 interface. The critical differences are:

- o FlexE channelized sub-interfaces guarantee a deterministic bandwidth for an LSP.
- o FlexE allows for creating very large end to end bandwidth

#### 7. Operations, Administration, and Maintenance (OAM)

To be added in a later version.

#### 8. Acknowledgements

#### 9. IANA Considerations

This memo includes no request to IANA.

Note to the RFC Editor: This section should be removed before publishing.

#### 10. Security Considerations

To be added in a later version.

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GMPLS Routing and Signaling Framework for Flexible Ethernet (FlexE)  
draft-izh-ccamp-flex-e-fwk-07

## Abstract

This document specifies the GMPLS control plane requirements, framework, and architecture for the FlexE technology. The document also discusses interoperation between the GMPLS control plane for FlexE and the control plane of any networking layer using the FlexE technology as a server layer.

As different from earlier Ethernet data planes FlexE allows for decoupling of the Ethernet Physical layer (PHY) and Media Access Control layer (MAC) rates.

Study Group 15 (SG15) of the ITU-T has endorsed the FlexE Implementation Agreement from Optical Internetworking Forum (OIF) and included it, by reference, in some of their Recommendations.

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## 1. Introduction

This document specifies the GMPLS control plane requirements, framework, and architecture for the FlexE technology. The FlexE control plane requirements are found in an appendix.

Prior to FlexE Ethernet MAC rates were until constrained to match the rates of the Ethernet PHY(s). FlexE, specified by the OIF, allows MAC rates to be different from PHY rates. An OIF implementation agreement [OIFFLEXE1] allows for complete decoupling of the MAC and PHY rates. This has been further extended in [OIFFLEXE2].

SG15 in ITU-T has endorsed the OIF FlexE data plane and parts of [G.872], [G.709], [G.798] and [G.8021]. The Recommendations depends on or are based on the FlexE data plane.

The FlexE implementation agreement includes support for:

- a. MAC rates which are greater than the rate of a single PHY; multiple PHYs are bonded to achieve this
- b. MAC rates which are less than the rate of a PHY (sub-rate)
- c. support for channelization within a single PHY, or over a group of bonded PHYs.

The capabilities supported by the FlexE data plane are:

- a. Support a large rate Ethernet MAC over bonded Ethernet PHYs, e.g. supporting a 200G MAC over 2 bonded 100GBASE-R PHY(s)
- b. Support a sub-rate Ethernet MAC over a single Ethernet PHY, e.g. supporting a 50G MAC over a 100GBASE-R PHY

- c. Support a collection of flexible Ethernet clients over a single Ethernet PHY, e.g. supporting two MACs with the rates 25Gbps, and one with rate 50G over a single 100GBASE-R PHY
- d. Support a sub-rate Ethernet MAC over bonded PHYs, e.g. supporting a 150G Ethernet client over 2 bonded 100GBASE-R PHY(s)
- e. Support a collection of Ethernet MAC clients over bonded Ethernet PHYs, e.g. supporting a 50G and 150G MAC over 2 bonded 100GBASE-R PHY(s)

FlexE networks feature FlexE Ethernet interfaces, for more details see Section 4.1.

From a control plane perspective, the FlexE Groups may be viewed as logical links and FlexE Clients as logical sub-interfaces (or channelized interfaces).

These logical point-to-point links may be realized in at least two different ways:

- a. direct point-to-point links with no intervening transport network.
- b. direct point-to-point links across a transport network transport network.
- c. Ethernet PHY(s) may be transparently transported via an Optical Transport Network (OTN), as defined by ITU-T in [G.709] and [G.798].

The OTN set of client mappings has been extended to support the use cases identified in the OIF FlexE implementation agreement.

This document is a framework for the network control plane signaling and routing extensions required to establish FlexE links (FlexE Groups (PHY) and FlexE Clients (MAC)). FlexE Links may interconnect customer edge devices (CE to CE), CE to provider edge devices (PE), PE to PE, or devices at the edge to devices in the core (PE to P) or devices in the core (P to P).

Any pair of neighbouring L2 and L3 device that support FlexE interfaces may be interconnected P2P using a FlexE link (PHY and MAC). Further a device that terminates a FlexE link MUST be able to extract either the L2 or L3 payload and switch on the appropriate level, i.e. Ethernet, MPLS or IP. It should be noted that any type of switching is outside of scope for the FlexE specification.

FlexE CE devices may typically be L3 routers or other devices that use FlexE at layers 1 and 2 to provide point-to-point connectivity between each other.

Thus this draft considers the cases in which the two peer FlexE devices are:

- o interconnecting two parts of a customer network (CE to CE).
- o at the edge of the customer network (CE) and the close edge of the provider network (PE to CE).
- o opposite edges of the FlexE capable network (PE to PE).
- o at the edge of the FlexE network PE interconnected to a provider device (PE to P).
- o interconnecting two provider devices (P to P).

This list of deployment cases will help identify the GMPLS control plane (i.e. routing and signaling) extensions that may be required to support establishment of FlexE services.

#### 1.1. Requirements Language

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

#### 1.2. Updates in the version

This section will be removed before posting.

1. Following a suggestion from Daniele the FlexE Control Plane Requirements has been moved to an appendix.
2. There are still some of the comments from Daniele that might need to be addressed, but we have had a pretty large overlap in comments, so the intention is that all should be addressed.
3. The terms Ethernet Interface and Ethernet sub-Interface has been re-introduced in relation to FlexE Group and FlexE Client respectively.



4. Except for some spelling corrections Section 5 to Section 7 are virtually untouched, though it is likely that some of the changes in the earlier parts of the document will have to be reflected into those sections also.

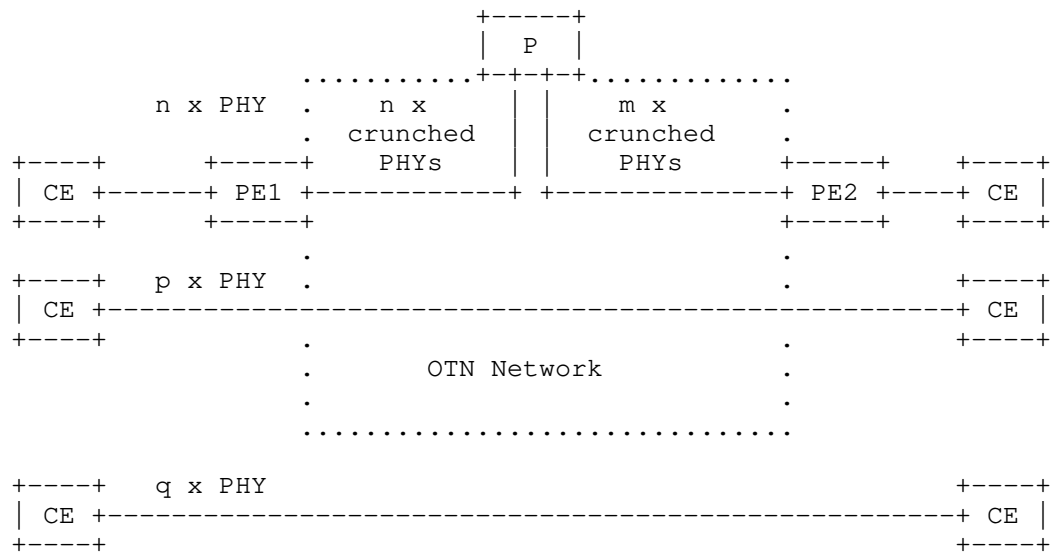
## 2. Terminology

- a. CE (Customer Edge): the group of functions that support the termination/origination of data received from or sent to the network. Sometimes the term CE device is used.
- b. controller: a joint term for any entity that may set up a LSP, FlexE Group or FlexE Client, e.g. a control plane, centralized controller, YANG model or management system.
- c. crunch: the term crunch in the context of OTN networks and FlexE links is used when e.g. unavailable calendar slots are not transported across the OTN network, but are removed at the ingress and recreated at the egress.
- d. Ethernet PHY: an entity representing Physical Coding Sublayer (PCS), Physical Media Attachment (PMA), and Physical Media Dependent (PMD) layers.
- e. FlexE Calendar: The total capacity of a FlexE Group is represented as a collection of slots which have a granularity of 5Gbps. The calendar for a FlexE Group composed of  $n$  100G PHYs is represented as an array of  $20n$  slots (each representing 5Gbps of bandwidth). This calendar is partitioned into sub-calendars, with 20 slots per 100G PHY. Each FlexE Client is mapped into one or more calendar slots (based on the bandwidth the FlexE Client flow will need).
- f. FlexE Channelized sub-Interface, the channelized Ethernet sub-interface realized by the FlexE Client.
- g. FlexE Client: An Ethernet flow based on a MAC data rate that may or may not correspond to any Ethernet PHY rate.
- h. FlexE Group: A FlexE Group is composed of from 1 to  $n$  Ethernet PHYs. In the first version of FlexE each PHY is identified by a number in the range {1-254}.
- i. FlexE Interface, the Ethernet interface realized the FlexE Group
- j. FlexE Shim: the layer that maps or demaps the FlexE Client flows carried over a FlexE Group.

- k. LMP: Link Management Protocol
- l. LSP: Label Switched Path
- m. OIF: Optical Internetworking Forum
- n. OTN: Optical Transport Network
- o. PE: Provider Edge (device) the term is used for the functions needed at the edge of a provider network or the device to which these functions are allocated.
- p. P: Provider (device), the term is used for the functions needed in the core of a provider network or the device to which these functions are allocated.
- q. SG15: ITU-T Study Group 15 (Transport, Access and Home).
- r. TE: Traffic Engineering
- s. TED: Traffic Engineering Database

### 3. FlexE Reference Model

The figure below gives a simplified FlexE reference model.



Legend: m, n, p and q indicate how many PHYS there are in a FlexE Group

Figure 1: FlexE Reference Model

The services offered by Flexible Ethernet are essentially the same as for traditional Ethernet, connection less Ethernet transport. In essence the FlexE interfaces and links may be viewed as any other Ethernet interfaces or links. However, it is possible to capture additional TE information in the Traffic Engineering Data Base showing unique characteristics of FlexE channelized interfaces and links. This makes it possible for the control plane to strategically use FlexE networks to support advanced TE.

#### 4. GMPLS Controlled FlexE

The high level goals for using a GMPLS control plane for FlexE can be summarized as:

- o Set up a FlexE Group
- o Set up a FlexE Client
- o Advertise the TE information of FlexE Groups and FlexE Clients

- o Set up of a higher layer LSPs that require to be (or would have significant benefits to) be run over a FlexE infrastructure.
- o Decoupling PHY and MAC bandwidth opens up some interesting features for networks that features FlexE links. By establishing several FlexE Clients with bandwidth that are part of the bandwidth of the FlexE Group, it is possible to create channels between to nodes.
- o By controlling the mapping a user packets (or frames) to these channels it is possible to create bandwidth that are dedicated for special purposes, and that can't be infringed on by packets (or frames) that does not satisfy this mapping.

#### 4.1. Interfaces in a FlexE network

FlexE Ethernet interfaces are realized by the means of a basic building block. The same building block is used for a single PHY and when the PHY's are bonded. The building block consists of two FlexE Shim functions (see Section 5.2.2.2) and a logical point to point link. The FlexE Shim functions are located at each end of the logical point to point link. This link carries the Ethernet PHY signals between the two FlexE Shim Functions.

#### 4.2. Mapping of traffic in the data plane

An example of which data plane mappings takes place when an upper layer, e.g. IP or MPLS, send packets over a FlexE interfaces is shown in Figure 2.

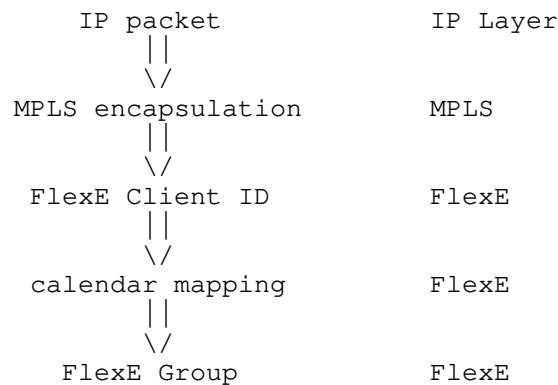


Figure 2: Traffic Mapping

In the mapping steps indicated in Figure 2 only one step in the mapping is visible by each layer.

- o the MPLS layer knows from the IP address, which MPLS label stack to encapsulate the IP packet in
- o the MPLS layer also know which MPLS label(s) that maps to which FlexE Client
- o the FlexE layer also knows from the FlexE Client Identifier, which calendar slots the packet will be transferred over
- o the FlexE layer knows which FlexE Group a certain set of calendar slots belongs too

#### 4.3. The GMPLS Control Plane and the FlexE identifiers

This section lists some of the procedures and actions on FlexE Interface Identifiers that a GMPLS Control plane need to perform. Also, a centralized controller, YANG model or a management system that are used to establish interfaces and links need to perform the same actions.

The FlexE Group Identifier and the FlexE Client Identifier, included in the overhead of each frame sent over a FlexE Interface or sub-Interface, indicates a particular Group or Client.

When the Control Plane, a centralized controller, a YANG model or a management system sets up a FlexE Interface at least the bandwidth

has to be included in the setup message. The FlexE system returns the FlexE Group Identifier in the response message.

When a channelized sub-interface is set up, the party that initiates the setup includes the Interface (FlexE Group) Identifier over which the sub-Interface will be established, and the bandwidth requested for the sub-interface. The FlexE system returns the FlexE Client Identifier.

The identifiers received by the party that initiates a setup of an FlexE Interface are used, by a controller, to set up FlexE sub-interfaces.

The identifiers received by the party that initiates a setup of an FlexE sub-Interface are used, e.g. to map an MPLS label to the correct FlexE sub-interfaces.

#### 4.4. Operational concerns

When operating a link in a FlexE network it is likely that an operator would like to split the FlexE Interface in sub-Interfaces used for best effort traffic and sub-Interfaces for dedicated for special purposes. An example would be when there is a 100 Gbit/s FlexE interface split into five 10 Gbit/s sub-interfaces and one 50 Gbit/s sub-interface. The 50 Gbit/s sub-interface could be used for best effort traffic, the five 10 Gbit/s could be used for dedicated traffic.

In such cases it is conceivable that packets/frames that have a matching key will be put on a specific sub-Interface, while traffic that does not have a matching key will be put on the best effort sub-interface.

#### 4.5. Pre-configured vs. Control Plane established LSPs in a FlexE capable network

The FlexE infrastructure may be established in three different ways

- o The FlexE Groups and FlexE Client may be pre-configured
- o Only the FlexE Groups may be pre-configured, while the setup of the FlexE Client is triggered by the request to setup a MPLS LSP.
- o The setup of both FlexE Group and FlexE Client may be triggered by the request to setup an MPLS LSP.

In the case the FlexE Groups and FlexE Clients are preconfigured the FlexE capable nodes need to have the ability to announce the preconfigured FlexE Client and/or FlexE Groups as if they were LSPs.

#### 4.6. Signaling Channel

In the type of equipment for which FlexE was first specified an out of band signaling channel is not commonly available. If that is the case, and the GMPLS FlexE control plane will be used, the FlexE Group will have to setup by e.g. a management system and a FlexE Client on that FlexE Group (also configured) will have to allocated as a signaling channel.

Further details of the setup of the FlexE Groups, FlexE Clients and MPLS LSPs over a FlexE infrastructure will be found in Section 6.2.

#### 4.7. MPLS LSP over the FlexE Data Plane

FlexE is a true link layer technology, i.e. it is not switched, this means that the FlexE Groups and FlexE Clients are terminated on the next-hop node, and that the switching needs to take place on a higher layer.

The FlexE technology can be used to establish link layer connectivity with high and deterministic bandwidth. However, there is no way described in the FlexE specification to, in a deterministic way, allocate certain traffic to a specific FlexE Client. Control of the FlexE link layer by a GMPLS control plane can achieve this.

A GMPLS controlled FlexE capable node may be thought of using the traditional model of a node with a separation between control and data plane.

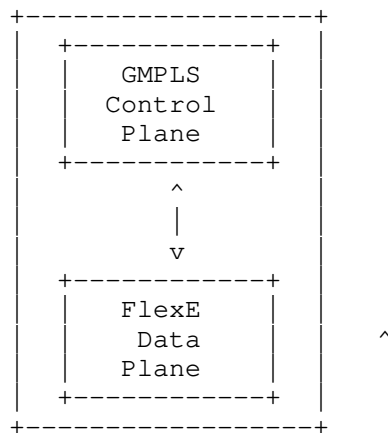


Figure 3: GMPLS controlled FlexE Node

The GMPLS control plane will speak extended standard GMPLS protocols with its neighbours and peers.

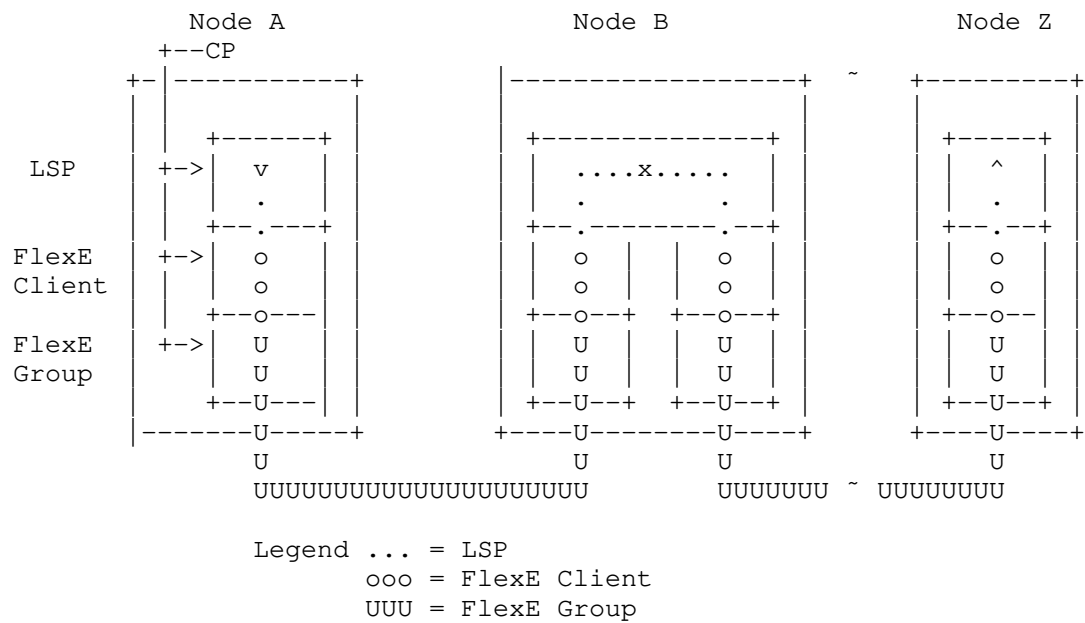


Figure 4: GMPLS controlled network with FlexE infrastructure



Figure 4 describes how an MPLS LSP is mapped over a FlexE Client and FlexE Group.

#### 4.8. Configuring the data plane in FlexE capable nodes

In Figure 4 we show an LSP, a FlexE Client and a FlexE Group, the LSP is there because while the FlexE Channel and Group are not switched, switching in our example takes place on the LSP level. This section will discuss establishment of FlexE Clients and Groups, and mapping of the LSP onto a FlexE Client.

The establishment of a LSP over a FlexE system is very similar to how this is done in any other system. Building on information gathered through the routing system and using the GMPLS signaling to establish the LSP.

##### 4.8.1. Configure/Establish a FlexE Group/Link

Consider the setup of a FlexE Group between node A and B, corresponding to the row of U's from node A to B in Figure 4. The FlexE Group is considered to consist of n PHYs, but does not have any FlexE Clients defined from start.

When this is done by the GMPLS control plane, two conditions need to be fulfilled (1) there need to be a data channel defined between node A and B; and (2) a FlexE capable IGP-TE protocol needs to be running in the network.

Node A will send an RSVP-TE message to node B with the information describing the FlexE Group to be setup. This information might be thought of as the "FlexE Group Label" (or part of the FlexE label). It will contain at least the following information:

- o A FlexE Group Identifier (FGid).
- o The number of active FlexE Channels (numFC), where 0 indicates that zero clients are active.
- o Number of PHYs that the FlexE Group is composed of, for each PHY
  - \* PHY identifier
  - \* PHY bandwidth
  - \* slot granularity/number of slots
  - \* available and unavailable slots

When node B receives the RSVP-TE message it checks that it can setup the requested FlexE Group. If the check turns positive, node send an acknowledgment to node A and the FlexE Group is setup.

A more detailed description of how to setup a FlexE Group, will be included in the draft dealing with signaling in detail.

#### 4.8.2. Configure/Establish a FlexE Client

Consider the situation where a FlexE Group is already established (as described in Section 4.8.1) and an m G FlexE Client is needed. Similar to the establishment of the FlexE Group, node A will send a RSV-TE message to node B.

This RSVP-TE message include at least the following information:

- o FlexE Group Identifier
- o FlexE Client Identifier
- o from which PHYs the slots will allocated, i.e. slots might come from more than one PHY.
- o Information per PHY
  - \* PHY bandwidth
  - \* slot granularity
  - \* available/unavailable slots
  - \* allocated slots

A more detailed description of how to setup a FlexE Channel, will be included in the draft dealing with signaling in detail.

#### 4.8.3. Advertise FlexE Groups and FlexE Clients

Once the FlexE Group and FlexE Clients are configured they can be advertised into the routing system as normal routing adjacencies, including the FlexE specific TE information.

### 5. Framework and Architecture

This section discusses FlexE framework and architecture. Framework is taken to mean how FlexE interoperates with other parts of the data communication system. Architecture is taken to mean how functional groups and elements within FlexE work together to deliver the

expected FlexE services. Framework is taken to mean how FlexE interacts with its environment.

### 5.1. FlexE Framework

The service offered by Flexible Ethernet is a transport service very similar (or even identical) to the service offered by Ethernet.

There are two major additions supported by FlexE:

- o FlexE is intended to support high bandwidth and FlexE can offer granular bandwidth from 5Gbits/s and a bandwidth as high as the FlexE Group allows.
- o As FlexE Groups and clients are setup as a configuration activity, by a centralized controller or by a GMPLS control plane the service is connection oriented.

### 5.2. FlexE Architecture

#### 5.2.1. Architecture Components

This section discusses the different parts of FlexE signaling and routing and how these parts interoperate.

The FlexE routing mechanism is used to provide resource available information for setup of higher layer LSPs, like Ethernet PHYs' information, partial-rate support information. Based on the resource available information advertised by routing protocol, an end-to-end FlexE connection is computed, and then the signaling protocol is used to set up the end-to-end connection.

FlexE signaling mechanism is used to setup LSPs.

MPLS forwarding over a FlexE infrastructure is different from forwarding over other infrastructures. When MPLS runs over a FlexE infrastructure it is possible that there are more than FlexE Client that meet the next-hop requirements, often it is possible to use any suitable FlexE Client for a hop between two nodes. If the mapping between a MPLS encapsulated packet and the FlexE Client, this mapping need to be explicit when the LSP is set up, and the MPLS label will be used to find the correct FlexE Client.

#### 5.2.2. FlexE Layer Model

The FlexE layer model is similar Ethernet model, the Ethernet PHY layer corresponds to the "FlexE Group", and the MAC layer corresponds to the "FlexE Client".

As different from earlier Ethernet the combination of FlexE Group and Client allows for a huge freedom when it comes to define the bandwidth of an Ethernet connectivity.

#### 5.2.2.1. FlexE Group structure

The FlexE Group might be supported by virtually any transport network, including the Ethernet PHY. While the Ethernet PHY offers a fixed bandwidth the FlexE Group has been structured into 5 Gbit/s slots. This means that the FlexE Group can support FlexE Clients of a variety of bandwidths.

The first version is defined for 20 slots of 5 Gbit/s over a 100 Gbit/s PHY. The 100 Gbit/s PHYs can be bonded to give higher bandwidth.

#### 5.2.2.2. FlexE Client mapping

A FlexE Client is an Ethernet flow based on a MAC data rate that may or may not correspond to any Ethernet PHY rate. The FlexE Shim is the layer that maps or demaps the FlexE Client flows carried over a FlexE Group. As defined in [OIFFLEXE1], MAC rates of 10, 40, and any multiple of 25 Gbit/s are supported. This means that if there is a 100 Gbit/s FlexE Group between A and B, a FlexE Client of 10, 25, 40, 50, 75 and 100 Gbit/s can be created.

However, by bonding, for example 5 PHYs of 100 Gbit/s to a single FlexE Group, FlexE Clients of 500 Gbit/s can be supported.

### 6. Control Plane

This section discusses the procedures and extensions needed to the GMPLS Control Plane to establish FlexE LSPs.

There are several ways to establish FlexE Groups, allocate slots for FlexE Clients, and setup higher layer LSPs. A configuration tool, a centralized controller or the GMPLS control plane can all be used.

To create the FlexE GMPLS control plane Groups, FlexE Clients and higher layer LSPs, extensions to the following protocols may be needed:

- o "RSVP-TE: Extensions to RSVP for LSP Tunnels" (RSVP-TE) [RFC3209]
- o "Link Management Protocol" (LMP) [RFC4204]
- o "Path Computation Element (PCE) Communication Protocol" (PCEP) [RFC5440]

- o IS-IS Extensions for Traffic Engineering (ISIS-TE) [RFC5305]
- o "OSPF Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)" (OSPF-TE) [RFC4203]
- o "North-Bound Distribution of Link-State and Traffic Engineering (TE) Information Using BGP" (BGP-LS) [RFC7752]

A FlexE control plane YANG model will also be needed.

Section 6.2 and Section 6.1 discusses the role of the GMPLS control plane when primarily setting up LSPs.

When discussing the signaling and routing procedures we assume that the FlexE Group has been established prior to executing the procedures needed to establish an LSP. Technically it is possible to establish FlexE Group, allocate FlexE Client slots and LSP with a single exchange of GMPLS signaling messages.

#### 6.1. GMPLS Routing

To establish an LSP the Traffic Engineering (TE) information is the most critical information, e.g. resource utilization on interfaces and link, including the availability of slots on the FlexE Groups. The GMPLS routing protocols needs to be extended to handle this information. The Traffic Engineering Database (TED) will keep an updated version of this information.

The FlexE capable nodes will be identified by IP-addresses, and the routing and traffic engineering information will be flooded to all nodes within the routing domain using TCP/IP.

When an LSP over the FlexE infrastructure is about to be setup, e.g. R1 - R4 - R5 in Figure 5 the information in the TED is used verify that resources are available. When it is conformed that the LSP is established the TED is updated, marking the resources used for the new LSP as used. Similarly, when a LSP is taken down the resources are marked as free.

#### 6.2. GMPLS Signaling

As described in Section 4 the state of the FlexE infrastructure may effect the actions needed to setup an LSP in a FlexE capable network. The FlexE infrastructure maybe be:

1. fully pre-configured

2. partially pre-configured, i.e. the FlexE Group may be pre-configured, but not the FlexE Clients
3. not pre-configured, i.e. the setup of FlexE Group and FlexE Client will be triggered because of the request to setup an LSP.

Figure 5 will be used to illustrate the different cases.

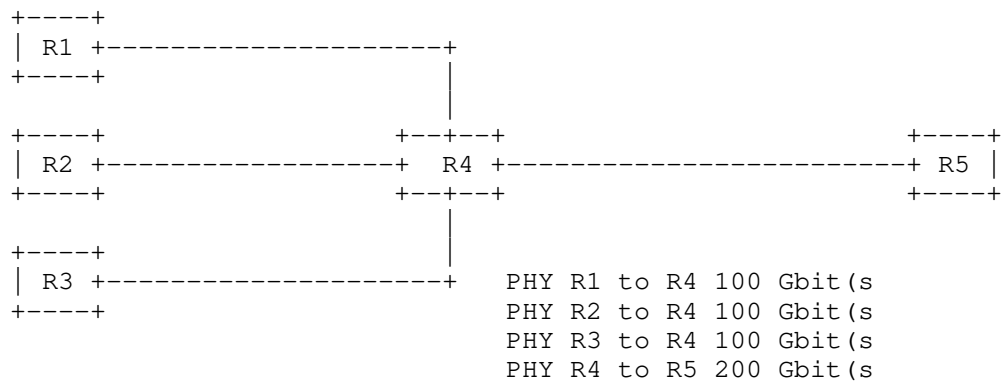


Figure 5: FlexE LSP Example

The text in Section 6.2 is not a specification of the GMPLS signaling extensions for FlexE capable network, it is a description to illustrate the expected features of such a protocol. Nor do we discuss failure scenarios.

#### 6.2.1. LSP setup with pre-configured FlexE infrastructure

In this first example, referencing Figure 5, one 100 Gbit/s FlexE Group is configured between R1 and R4, between R2 and R4, and between R3 and R4. Between R4 and R5 there is a 200 Gbit/s FlexE Group.

Over each 100 Gbit/s FlexE Group there are four 5 Gbit/s, two 20 Gbit/s and one 40 Gbit/s FlexE Clients configured. Over the 200 Gbit/s FlexE Group there are eight 5 Gbit/s, four 20 Gbit/s and two 40 Gbit/s FlexE Clients configured.

One of the 5 Gbit/s FlexE Clients on each FlexE Groups are used as signaling channel.

To establish the for example a 200 Mbit/s MPLS LSP the normal GMPLS request/response procedures are followed. R1 sends the request to R4, R4 allocate resources on one of the FlexE Clients, forward the request to R5. R5 responds to R4 indicating the label and the FlexE Client the traffic should be sent over, R4 does the same for R1.

The only difference between the standard signaling and what happens here is that there the assigned label will be used to find the right FlexE Client.

#### 6.2.2. LSP setup with partially configured FlexE infrastructure

In the second example, also referencing Figure 5, the FlexE Groups are setup in the same way as in the first example, however only one 5 Gbit/s FlexE Client per FlexE Group are established by configuration. This FlexE Client will be used for signaling.

When preparing to send the request that a 5 Gbit/s MPLS LSP shall be set up R1 discovers that there are no feasible FlexE Client between R1 and R4. R1 therefore sends the request to establish such a FlexE Client, when receiving the request R4 allocates resources for the FlexE Client on the FlexE Group. There may be different strategies for allocating the bandwidth for this FlexE Client. Such strategies are out of scope for this document. R1 then sends the information about the FlexE Client to R1, and both ends establish the FlexE Client.

When the FlexE Client between R1 and R4 is established, R1 proceeds to send the request for an MPLS LSP to R4. R4 will discover that a feasible FlexE Client is missing between R4 and R5. The same procedure s for setting up the FlexE Client between R1 and R4 is repeated for R4 and R5. When there is a feasible FlexE Client available the signaling to set up the MPLS LSP continues as normal.

The label allocated for the MPLS LSP will be used to find the correct FlexE Client.

When a FlexE Clients is set up in this way they can be announced into the routing system in two different ways. First, they can be made generally available, i.e. it will be free to use for anyone that want to set up LSPs over the FlexE Group between R1 and R4 and between R4 and R5. Second, the use of the FlexE Clients may be restricted to the application that initially did set up the FlexE Client.

### 6.2.3. LSP setup with non-configured FlexE infrastructure

This example also refers to Figure 5 as different from the earlier example no FlexE Group or FlexE Client configuration is done prior to the first request for an MPLS LSP over the FlexE infrastructure.

To make the set up of LSPs in a FlexE network where no FlexE Groups or FlexE Clients have been configured two conditions need to be fulfilled. First an out of band signaling channel must be available. Second the FlexE Capabilities must be announced in to the IGP and/or centralized controller.

If these two conditions are fulfilled, the set up of an MPLS LSP progress pretty much as in the partially configured network. The difference is that the set up of both the FlexE Group and FlexE Client are triggered by the request to set up an MPLS LSP.

As in the partially configured case FlexE Clients can be announced into the routing system in two different modes, either they are generally available. It or they are reserved for the applications that first established them.

### 6.2.4. Packet Label Switching Data Plane

This section discusses how the FlexE LSP data plane works. In general it can be said that the interface offered by the FlexE Shim and the FlexE Client is equivalent to the interface offered by the Ethernet MAC.

Figure 6 below illustrates the FlexE packet switching data plane procedures.



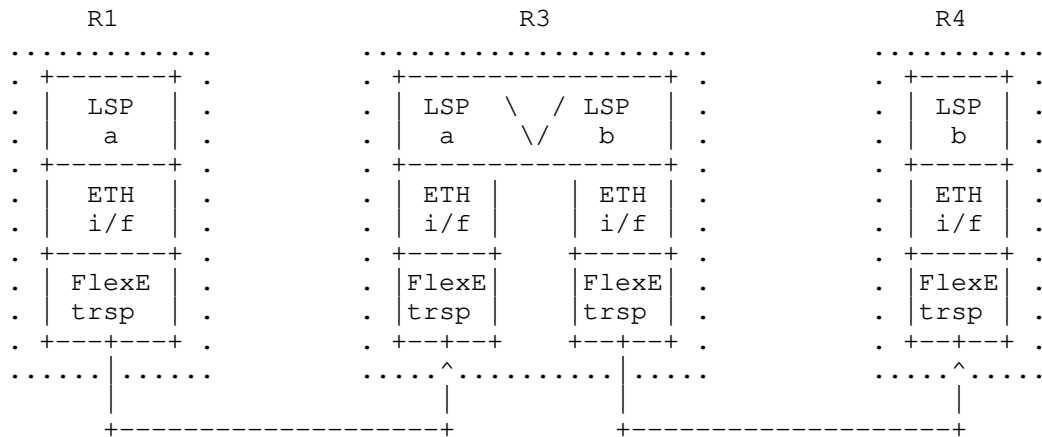


Figure 6: LSP over FlexE Data Plane

The data plane processes packets like this:

- o The LSP encapsulating and forwarding function in node R1 receives a packet that needs to be encapsulated as an MPLS packet with the label "a". The label "a" is used to figure out which FlexE emulated Ethernet interfaces the label encapsulated packet need to be forwarded over.
- o The Ethernet interfaces, by means of FlexE transport, forwards the packet to node R3. Node R3 swaps the label "a" to label "b" and uses "b" to decide over which interface to send the packet.
- o Node R3 forwards the packet to node R, which terminates the LSP.

Sending MPLS encapsulated packets over a FlexE Client is similar to send them over an Ethernet 802.1 interface. The critical differences are:

- o FlexE channelized sub-interfaces guarantee a deterministic bandwidth for an LSP.
- o When a application that originally establish a FlexE Client reserve it for use by that application only, it is possible to create unfringeable bandwidth end-to-end for an MPLS LSP.
- o FlexE infrastructure allows for creating very large end to end bandwidth

## 7. Operations, Administration, and Maintenance (OAM)

To be added in a later version.

## 8. Acknowledgements

## 9. IANA Considerations

This memo includes no request to IANA.

Note to the RFC Editor: This section should be removed before publishing.

## 10. Security Considerations

To be added in a later version.

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## 12.2. Informative References

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## Appendix A. Requirements

This section summarizes the signaling and routing requirements for a FlexE control plane, with respect to establishing FlexE Groups, FlexE Clients and MPLS LSPs that require support from an FlexE infrastructure.

Req-1 The FlexE control plane SHALL support the creation of FlexE Groups.

- \* A FlexE Groups consist one or more 100GE Ethernet PHY(s). In the first version of FlexE the number of PHYs are in the range of 1 to 254.
- \* This requirement can be met by several methods, e.g. routing and signaling protocols, a centralized controller or a management system.

Any such method need to have network access to the FlexE shims at each of the Ethernet PHY(s) termination points.

Req-2 The FlexE control plane SHALL have the ability to delete a FlexE Group.

Req-3 The FlexE control plane SHALL have the ability to initiate an administratively lock or unlock of a FlexE Group.

- \* This ability is needed e.g. for executing the next requirement.

Req-4 When a FlexE Group has been administratively looked is SHALL be possible to add PHYs to an operational FlexE Group.

Req-5 When a FlexE Group has been administratively looked is SHALL be possible to remove PHYs from an operational FlexE Group.

Req-6 The FlexE control plane SHALL support the ability to collect, advertise and discover information about FlexE capable nodes, including the TE information the FlexE Groups and FlexE Clients the nodes support.

Note: In essence correct, but something is backward. Need to think.

Req-7 The FlexE control plane SHALL allow the addition (or removal) of one or more FlexE clients to a FlexE Group. The addition (or removal) of a FlexE Client flow SHALL NOT affect the services of the other FlexE Client signals.

Req-8 The FlexE control plane SHALL, though this MAY not be possible in all network scenarios, support FlexE Client flow resizing without affecting any existing FlexE Clients within the same FlexE Group.

Req-9 The FlexE control plane SHALL support establishment of MPLS LSPs that requires the support of a FlexE infrastructure.

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A Yang Data Model for WSON Tunnel

draft-lee-ccamp-wson-tunnel-model-01.txt

## Abstract

This document provides a YANG data model for WSON TE tunnel.

## Status of this Memo

This Internet-Draft is submitted to IETF in full conformance with the provisions of BCP 78 and BCP 79.

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## 1. Introduction

This document provides a YANG data model for WSON tunnel model. The YANG model described in this document is a WSON technology-specific Yang Tunnel 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].

This document augments the generic TE tunnel model [TE-Tunnel].

## 2. YANG Model (Tree Structure)

```

module: ietf-te-wson
  augment /te:te/te:tunnels/te:tunnel/te:config:
    +--rw wavelength-assignment?  identityref
    +--rw selected-frequency?      decimal64
    +--rw channel-spacing?         decimal64
    +--rw resource-pool* [resource-pool-id]

```



```

    +--rw resource-pool-id      uint32
    +--rw pool-state?          boolean
    +--rw matrix-interface* [in-port-id]
        +--rw in-port-id      wson-interface-ref
        +--rw out-port-id?    wson-interface-ref
augment /te:te/te:tunnels/te:tunnel/te:state:
    +--ro wavelength-assignment? identityref
    +--ro selected-frequency?    decimal64
    +--ro channel-spacing?       decimal64
    +--ro resource-pool* [resource-pool-id]
        +--ro resource-pool-id  uint32
        +--ro pool-state?      boolean
        +--ro matrix-interface* [in-port-id]
            +--ro in-port-id    wson-interface-ref
            +--ro out-port-id?  wson-interface-ref
augment /te:te/te:lsps-state/te:lsp:
    +--ro wavelength-assignment? identityref
    +--ro selected-frequency?    decimal64
    +--ro channel-spacing?       decimal64
    +--ro resource-pool* [resource-pool-id]
        +--ro resource-pool-id  uint32
        +--ro pool-state?      boolean
        +--ro matrix-interface* [in-port-id]
            +--ro in-port-id    wson-interface-ref
            +--ro out-port-id?  wson-interface-ref
augment /te:te/te-dev:interfaces/te-dev:interface:
    +--rw selected-frequency?    decimal64
    +--rw channel-spacing?       decimal64

```

### 3. TE Tunnel Model for WSON

<CODE BEGINS> file "ietf-te-wson@2017-06-27.yang"

```

module ietf-te-wson{

    namespace "urn:ietf:params:xml:ns:yang:ietf-te-wson";

    prefix "te-wson";

    import ietf-te {
        prefix "te";
    }

    import ietf-te-device {
        prefix "te-dev";
    }
}

```

```
import ietf-wson-topology {
  prefix "wson";
}

organization
  "IETF CCAMP Working Group";

contact
  "WG Web:    <http://tools.ietf.org/wg/ccamp/>
  WG List:    <mailto:ccamp@ietf.org>

  WG Chair: Daniele Ceccarelli
              <mailto:daniele.ceccarelli@ericsson.com>

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  Editor: Young Lee <leeyoung@huawei.com>
  Editor: Dhruv Dhody <dhruv.ietf@gmail.com>
  Editor: Ricard Vilalta <ricard.vilalta@cttc.es>";

description
  "Latest update to WSON TE YANG data model.";

revision "2017-06-27" {
  description "Update to add Resource Pool Model.";
  reference "version 1";
}

revision "2017-06-21" {
  description "Update to WSON TE YANG initial revision.";
  reference "version 0";
}

identity wavelength-assignment {
  description "Wavelength selection base";
}

identity unspecified-wavelength-assignment {
  base wavelength-assignment;
  description "No method specified";
}

identity first-fit-wavelength-assignment {
  base wavelength-assignment;
  description "All the available wavelengths are numbered,
    and this WA method chooses the available wavelength
```

```
        with the lowest index.";
    }

    identity random-wavelength-assignment {
        base wavelength-assignment;
        description "This WA method chooses an available
            wavelength randomly.";
    }

    identity least-loaded-wavelength-assignment {
        base wavelength-assignment;
        description "This WA method selects the wavelength that
            has the largest residual capacity on the most loaded
            link along the route (in multi-fiber networks).";
    }

    /* TE WSON LSPs groupings */
    grouping lsp-attributes-flags-wson_config {
        description
            "Configuration parameters relating to TE WSON LSP
            attribute flags";

        leaf wavelength-assignment {
            type identityref {
                base wavelength-assignment;
            }
            description "Wavelength Allocation Method";
        }

        leaf selected-frequency {
            type decimal64 {
                fraction-digits 5;
            }
            units THz;
            default 193.1;
            description "Selected Central Frequency";
        }

        leaf channel-spacing {
            type decimal64 {
                fraction-digits 5;
            }
            units GHz;
            description "This is fixed channel spacing for
                WSON, e.g, 12.5, 25, 50, 100, ..";
        }
        uses wson:resource-pool-attributes;
    }
}
```

```
grouping tunnel-properties-wson {
  description
    "Top level grouping for LSP properties.";
    uses lsp-attributes-flags-wson_config;
}

grouping lsp-properties-wson {
  description
    "Top level grouping for LSP properties.";
    uses lsp-attributes-flags-wson_config;
}
/* End of TE WSON LSPs groupings */

/**
 * Interface groupings
 */
grouping wson-reservable {
  description "Top level grouping for interface properties";
  leaf selected-frequency {
    type decimal64 {
      fraction-digits 5;
    }
    units THz;
    default 193.1;
    description "Selected Central Frequency";
  }

  leaf channel-spacing {
    type decimal64 {
      fraction-digits 5;
    }
    units GHz;
    description "This is fixed channel spacing for WSON,
      e.g, 12.5, 25, 50, 100, ..";
  }
}

/* End of interface groupings */

/**
 * Augmentation to TE generic module
 */
augment "/te:te/te:tunnels/te:tunnel/te:config" {
  description
    "Augmentations for WSON TE tunnel properties";
  uses tunnel-properties-wson;
}
```

```
augment "/te:te/te:tunnels/te:tunnel/te:state" {  
  description  
    "Augmentations for WSON TE tunnel properties";  
  uses tunnel-properties-wson;  
}  
  
augment "/te:te/te:lsps-state/te:lsp" {  
  description  
    " WSON LSP state properties";  
  uses lsp-properties-wson;  
}  
  
augment "/te:te/te-dev:interfaces/te-dev:interface" {  
  description  
    "WSON reservable bandwidth configuration properties";  
  uses wson-reservable;  
}  
  
}  
<CODE ENDS>
```

#### 4. Security Considerations

TDB

#### 5. IANA Considerations

TDB

#### 6. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.

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January 8, 2018

## A Yang Data Model for WSON Tunnel

draft-lee-ccamp-wson-tunnel-model-04.txt

### Abstract

This document provides a YANG data model for WSON TE tunnel.

### Status of this Memo

This Internet-Draft is submitted to IETF in full conformance with the provisions of BCP 78 and BCP 79.

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## 1. Introduction

This document provides a YANG data model for WSON tunnel model. The YANG model described in this document is a WSON technology-specific Yang Tunnel 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].

This document augments the generic TE tunnel model [TE-Tunnel].

## 2. YANG Model (Tree Structure)

module: ietf-wson-tunnel

```
augment /te:te/te:tunnels/te:tunnel:
  +--rw src-client-signal?  identityref
  +--rw dst-client-signal?  identityref
augment /te:te/te:tunnels/te:tunnel/te:state:
  +--ro src-client-signal?  identityref
  +--ro dst-client-signal?  identityref
augment /te:te/te:globals/te:named-path-constraints/te:named-path-
constraint:
  +--rw wavelength-assignment?  identityref
augment /te:tunnels-rpc/te:input/te:tunnel-info/tepc:request-list:
  +---- src-client-signal?      identityref
  +---- dst-client-signal?      identityref
  +---- wavelength-assignment?  identityref
```

### 3. TE Tunnel Model for WSON

<CODE BEGINS> file "ietf-wson-tunnel@2018-01-08.yang"

```
module ietf-wson-tunnel {
  //TODO: FIXME
  //yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-wson-tunnel";
  prefix "wson-tunnel";

  import ietf-te { prefix "te"; }
  import ietf-otn-types { prefix "otn-types"; }
  import ietf-te-wson-types { prefix "wson-types"; }
  import ietf-te-path-computation { prefix "tepc"; }

  organization
    "IETF CCAMP Working Group";

  contact
    "WG Web:    <http://tools.ietf.org/wg/ccamp/>
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    WG Chair: Daniele Ceccarelli
               <mailto:daniele.ceccarelli@ericsson.com>

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```

```
Editor: Young Lee <leeyoung@huawei.com>
Editor: Dhruv Dhody <dhruv.ietf@gmail.com>
Editor: Ricard Vilalta <ricard.vilalta@cttc.es>;
description
    "This module defines a model for WSON Tunnel Services.";

revision "2018-01-08" {
    description
        "Updates to version 4";
    reference "version 4";
}

grouping wson-tunnel-endpoint {
    description "Parameters for OTN tunnel.";

    leaf src-client-signal {
        type identityref {
            base otn-types:client-signal;
        }
        description
            "Client signal at the source endpoint of
            the tunnel.";
    }

    leaf dst-client-signal {
        type identityref {
            base otn-types:client-signal;
        }
        description
            "Client signal at the destination endpoint of
            the tunnel.";
    }
}

grouping wson-path-constraints {
    description
        "Global named path constraints configuration
        grouping for WSON tunnel";

    leaf wavelength-assignment {
        type identityref {
            base wson-types:wavelength-assignment;
        }
    }
}
```

```
        description "Wavelength Allocation Method";
    }
}

augment "/te:te/te:tunnels/te:tunnel" {
    description
        "Augment with additional parameters required for WSON
        tunnel.";
    uses wson-tunnel-endpoint;
}

augment "/te:te/te:tunnels/te:tunnel/te:state" {
    description
        "Augment with additional parameters required for WSON
        tunnel.";
    uses wson-tunnel-endpoint;
}

augment "/te:te/te:globals/te:named-path-constraints/"
+ "te:named-path-constraint" {
    description
        "Augment with additional constraints WSON
        tunnel.";
    uses wson-path-constraints;
}

augment "/te:tunnels-rpc/te:input/te:tunnel-info/"
+ "tepc:request-list" {
    description
        "Augment with additional constraints WSON
        tunnel.";
    uses wson-tunnel-endpoint;
    uses wson-path-constraints;
}

}
```

<CODE ENDS>

#### 4. 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 [RFC6536] 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 writable/deletable (i.e., "config true") These data nodes may be considered sensitive or vulnerable in some network environments.

## 5. IANA Considerations

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

```
-----  
URI: urn:ietf:params:xml:ns:yang:ietf-wson-tunnel  
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-wson-tunnel  
namespace:     urn:ietf:params:xml:ns:yang:ietf-wson-tunnel  
reference:     RFC XXXX (TDB)  
-----
```

## 6. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.

## 7. References

### 7.1. Normative References

[TE-TOPO] X. Liu, et al., "YANG Data Model for TE Topologies", work in progress: draft-ietf-teas-yang-te-topo.

### 7.2. Informative References

[RFC7446] Y. Lee, G. Bernstein, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, February 2015.

[RFC7579] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "General Network Element Constraint Encoding for GMPLS Controlled Networks", RFC 7579, November 2015.

[RFC7581] G. Bernstein, Y. Lee, D. Li, W. Imajuku, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, November 2015.

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Information Encoding for WSON with Impairments Validation  
draft-martinelli-ccamp-wson-iv-encode-08

Abstract

Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) function might be required in Wavelength Switched Optical Networks (WSON) that already support RWA. This document defines proper encoding to support this operation. It goes in addition to the available impairment-free WSON encoding and it is fully compatible with it.

As the information model, the encoding is independent from control plane architectures and protocol implementations. Its definitions can be used in related protocol extensions.

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## 1. Introduction

In case of WSON where optical impairments play a significant role, the framework document [RFC6566] defines related control plane architectural options for Impairment Aware Routing and Wavelength Assignment (IA-RWA). This document provides a suitable encoding for the related WSON impairment information model as defined [I-D.ietf-ccamp-wson-iv-info].

This document directly refers to ITU recommendations [ITU.G680] and [ITU.G697] as already detailed in the information model.

### 1.1. Requirements Language

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

## 2. Encoding

This section details encoding for all elements defined within [I-D.ietf-ccamp-wson-iv-info]. Elements to encode are:

Optical Parameter (OPTICAL\_PARAM)

Optical Impairment Vector (OIV)

Impairment Matrix

Impairment Resource Block Information

### 2.1. Optical Parameter

The OPTICAL\_PARAM is defined as a sub-TLV object.

0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1								
S V										Reserved										ParamSource										ParamID									
										Value																													
										Variance (Optional)																													

The following flag is defined:

S: Standard bit.

S=1 identifies a set of parameters standardized by ITU; while  
S=0 identifies a non-standardized set of parameters.

V: Variance bit.

V=0 only parameter value, V=1 parameter value and variance.

With the flag S=1 the following parameters are defined:

ParamSource = 1.

Identify the ITU document that defines the following parameter list. Currently [ITU.G697] defines this value 1 for this parameter.

**ParamID.**

Parameter identifier according to the source. [ITU.G697] table V.3 defines the following identifiers:

1. Total Power (dBm)  
Not reported within [I-D.ietf-ccamp-wson-iv-info] parameter list but relates to Channel Power through the number of channels.
2. Channel Power (dBm).  
Referred as parameter L-3 in [I-D.ietf-ccamp-wson-iv-info]
3. Reserved ("Frequency Deviation from Nominal, GHz", defined in [ITU.G697] but not used)
4. Reserved ("Wavelength Deviation from Nominal, nm", defined in [ITU.G697] but not used)
5. OSNR (db).  
Referred as parameter G-1 in [I-D.ietf-ccamp-wson-iv-info]
6. Reserved. (Q Factor, a pure number).  
Not reported within [I-D.ietf-ccamp-wson-iv-info] parameter list but is a known index for assessing channel quality.
7. PMD (ps).  
Referred as parameter G-3 in [I-D.ietf-ccamp-wson-iv-info]
8. Residual Chromatic Dispersion (ps/nm).  
Referred as parameter G-2 in [I-D.ietf-ccamp-wson-iv-info]

**Value.**

Value for the parameter. As defined by [ITU.G697], it is a 32 bit IEEE floating point number.

**Variance.**

Variance for the parameter, a 32 bit IEEE floating point number.

According to [I-D.ietf-ccamp-wson-iv-info], there are some parameters required for the IV function not listed within [ITU.G697]. Current information source for such parameters is [LS78] hence, this document proposes to use a different value for the field parameter source.

ParamSource = 0 (proposal).

List of parameters within [I-D.ietf-ccamp-wson-iv-info].

[Editor Note: Value to be confirmed through ITU Liaison].

ParamID.

A number that take the following list of values.

1. Ripple (dBm). L-4 in [I-D.ietf-ccamp-wson-iv-info].
2. Channel signal-spontaneous noise figure. L-5 in [I-D.ietf-ccamp-wson-iv-info].
3. DGD, Differential Group Delay. L-8 in [I-D.ietf-ccamp-wson-iv-info].
4. Reflectance. L-11 in [I-D.ietf-ccamp-wson-iv-info].
5. Isolation. L-12 in [I-D.ietf-ccamp-wson-iv-info].
6. Channel extinction. L-13 in [I-D.ietf-ccamp-wson-iv-info].
7. Attenuation Coefficient. L-14 in [I-D.ietf-ccamp-wson-iv-info].

## 2.2. Impairment Vector

This sub-TLV is a list of optical parameters and they MAY have a wavelength dependency information.

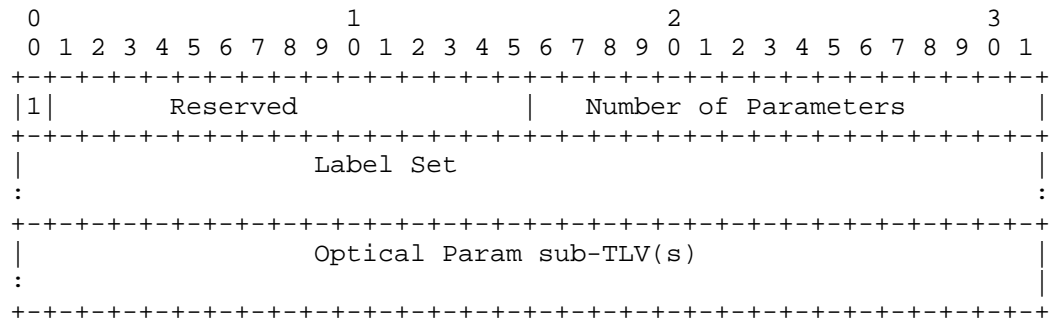
0										1										2										3																			
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9										
0										Reserved																				Number of Parameters																			
										Optical Param sub-TLV(s)																																							
:																																																	

Where:

W = 0. Wavelength Dependency flag. There is no wavelength dependency.

Number of Parameters contained in this vector.

Optical Param sub-TLV(s) present a list of Object as defined in Section 2.1.



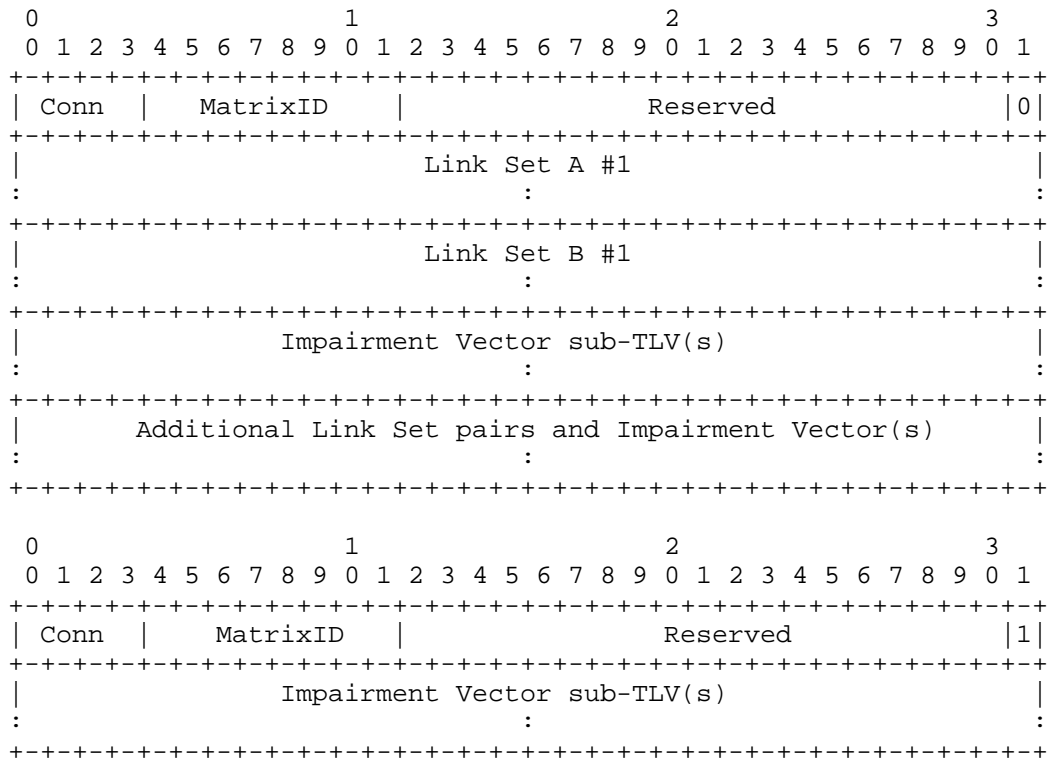
Where:

W = 1. Wavelength Dependency flag. There is wavelength dependency.

The Label Set object is defined in [RFC7579] Section 2.1. Likely an inclusive range will be the only option required by the Action defined in the Label Set.

### 2.3. Impairment Matrix

As defined by the [I-D.ietf-ccamp-wson-iv-info], the impairment matrix follows the same structure as the connectivity matrix.



Where:

Connectivity (Conn) (4 bits) has value 2 for the impairment matrix (Values 0 and 1 defined by [RFC7579]).

MatrixID: matrix identifier, following same rules as [RFC7579].

N: Node scope flag. With this flag set there's no Link Set information but only a list of optical parameters TLVs that apply to the whole optical node.

The usage of multiple matrixes with connectivity type equal to 2 (Impairment Matrix) MIGHT be used to group optical parameters by connectivity. For example, if a subset of parameters apply to the whole node, a unique matrix with flag N=1 is used. At the same some another subset of parameters applies only to some LinkSet pairs, a specific Impairment Matrix will be added.



## 2.4. Resource Block Information

As defined by [I-D.ietf-ccamp-wson-iv-info], the concept of resource block is extended to support the description of the impairments related to that block. The encoding follows the same structure as the one defined in [RFC7581], with the addition of an optional Impairment Vector sub-object:

```

0                               1                               2                               3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               RB Set Field                               |
+-----+-----+-----+-----+-----+-----+-----+-----+
| I | O |                               Reserved                               |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Optical Interface Class List(s) (opt)         |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Acceptable Client Signal Type (opt)           |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Input Bit Rate List (opt)                     |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               Processing Capabilities List (opt)             |
+-----+-----+-----+-----+-----+-----+-----+-----+
|                               OIV-Impairment Vector (opt)                   |
+-----+-----+-----+-----+-----+-----+-----+-----+

```

The Impairment Vector is defined within Section 2.2. All the other fields are defined within [RFC7581].

## 3. Acknowledgements

Authors would like to acknowledge Greg Bernstein and Moustafa Kattan as authors of a previous similar draft whose content partially converged here.

Authors would like to thank ITU SG15/Q6 and in particular Peter Stassar and Pete Anslow for providing useful information and text to CCAMP through join meetings and liaisons.

#### 4. IANA Considerations

This document does not contain any IANA request.

#### 5. Security Considerations

This document defines an protocol-neutral encoding for an information model describing impairments in optical networks and it does not introduce any security issues. If such a encoding is put into use within a network it will by its nature contain details of the physical characteristics of an optical network. Such information would need to be protected from intentional or unintentional disclosure.

#### 6. References

##### 6.1. Normative References

- [ITU.G680] International Telecommunications Union, "Physical transfer functions of optical network elements", ITU-T Recommendation G.680, July 2007.
- [ITU.G697] International Telecommunications Union, "Optical monitoring for dense wavelength division multiplexing systems", ITU-T Recommendation G.697, February 2012.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.

##### 6.2. Informative References

- [I-D.ietf-ccamp-wson-iv-info] Martinelli, G., Zhang, X., Galimberti, G., Zanardi, A., Siracusa, D., Pederzolli, F., Lee, Y., and F. Zhang, "Information Model for Wavelength Switched Optical Networks (WSONs) with Impairments Validation", draft-ietf-ccamp-wson-iv-info-04 (work in progress), March 2017.
- [LS78] International Telecommunications Union SG15/Q6, "LS/s on CCAMP Liaison to ITU-T SG15 Q6 and Q12 on WSON", LS <https://datatracker.ietf.org/liaison/1288/>, October 2013.

- [RFC6566] Lee, Y., Ed., Bernstein, G., Ed., Li, D., and G. Martinelli, "A Framework for the Control of Wavelength Switched Optical Networks (WSONs) with Impairments", RFC 6566, DOI 10.17487/RFC6566, March 2012, <<http://www.rfc-editor.org/info/rfc6566>>.
- [RFC7579] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "General Network Element Constraint Encoding for GMPLS-Controlled Networks", RFC 7579, DOI 10.17487/RFC7579, June 2015, <<http://www.rfc-editor.org/info/rfc7579>>.
- [RFC7581] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, DOI 10.17487/RFC7581, June 2015, <<http://www.rfc-editor.org/info/rfc7581>>.

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Information Encoding for WSON with Impairments Validation  
draft-martinelli-ccamp-wson-iv-encode-09

Abstract

Impairment-Aware (IA) Routing and Wavelength Assignment (RWA) function might be required in Wavelength Switched Optical Networks (WSON) that already support RWA. This document defines proper encoding to support this operation. It goes in addition to the available impairment-free WSON encoding and it is fully compatible with it.

As the information model, the encoding is independent from control plane architectures and protocol implementations. Its definitions can be used in related protocol extensions.

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## 1. Introduction

In case of WSON where optical impairments play a significant role, the framework document [RFC6566] defines related control plane architectural options for Impairment Aware Routing and Wavelength Assignment (IA-RWA). This document provides a suitable encoding for the related WSON impairment information model as defined [I-D.ietf-ccamp-wson-iv-info].

This document directly refers to ITU recommendations [ITU.G680] and [ITU.G697] as already detailed in the information model.

## 1.1. Requirements Language

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

## 2. Encoding

This section details encoding for all elements defined within [I-D.ietf-ccamp-wson-iv-info]. Elements to encode are:

Optical Parameter (OPTICAL\_PARAM)

Optical Impairment Vector (OIV)

Impairment Matrix

Impairment Resource Block Information

### 2.1. Optical Parameter

The OPTICAL\_PARAM is defined as a sub-TLV object.

0										1										2										3											
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1										
S V										Reserved										ParamSource										ParamID											
										Value																															
										Variance (Optional)																															

The following flag is defined:

S: Standard bit.

S=1 identifies a set of parameters standardized by ITU; while  
S=0 identifies a non-standardized set of parameters.

V: Variance bit.

V=0 only parameter value, V=1 parameter value and variance.

With the flag S=1 the following parameters are defined:

ParamSource = 1.

Identify the ITU document that defines the following parameter list. Currently [ITU.G697] defines this value 1 for this parameter.



ParamID.

Parameter identifier according to the source. [ITU.G697] table V.3 defines the following identifiers:

1. Total Power (dBm)  
Not reported within [I-D.ietf-ccamp-wson-iv-info] parameter list but relates to Channel Power through the number of channels.
2. Channel Power (dBm).  
Referred as parameter L-3 in [I-D.ietf-ccamp-wson-iv-info]
3. Reserved ("Frequency Deviation from Nominal, GHz", defined in [ITU.G697] but not used)
4. Reserved ("Wavelength Deviation from Nominal, nm", defined in [ITU.G697] but not used)
5. OSNR (db).  
Referred as parameter G-1 in [I-D.ietf-ccamp-wson-iv-info]
6. Reserved. (Q Factor, a pure number).  
Not reported within [I-D.ietf-ccamp-wson-iv-info] parameter list but is a known index for assessing channel quality.
7. PMD (ps).  
Referred as parameter G-3 in [I-D.ietf-ccamp-wson-iv-info]
8. Residual Chromatic Dispersion (ps/nm).  
Referred as parameter G-2 in [I-D.ietf-ccamp-wson-iv-info]

Value.

Value for the parameter. As defined by [ITU.G697], it is a 32 bit IEEE floating point number.

Variance.

Variance for the parameter, a 32 bit IEEE floating point number.

According to [I-D.ietf-ccamp-wson-iv-info], there are some parameters required for the IV function not listed within [ITU.G697]. Current information source for such parameters is [LS78] hence, this document proposes to use a different value for the field parameter source.

ParamSource = 0 (proposal).

List of parameters within [I-D.ietf-ccamp-wson-iv-info].

ParamID.

A number that take the following list of values.

1. Ripple (dBm). L-4 in [I-D.ietf-ccamp-wson-iv-info].
2. Channel signal-spontaneous noise figure. L-5 in [I-D.ietf-ccamp-wson-iv-info].
3. DGD, Differential Group Delay. L-8 in [I-D.ietf-ccamp-wson-iv-info].
4. Reflectance. L-11 in [I-D.ietf-ccamp-wson-iv-info].
5. Isolation. L-12 in [I-D.ietf-ccamp-wson-iv-info].
6. Channel extinction. L-13 in [I-D.ietf-ccamp-wson-iv-info].
7. Attenuation Coefficient. L-14 in [I-D.ietf-ccamp-wson-iv-info].

## 2.2. Impairment Vector

This sub-TLV is a list of optical parameters and they MAY have a wavelength dependency information.

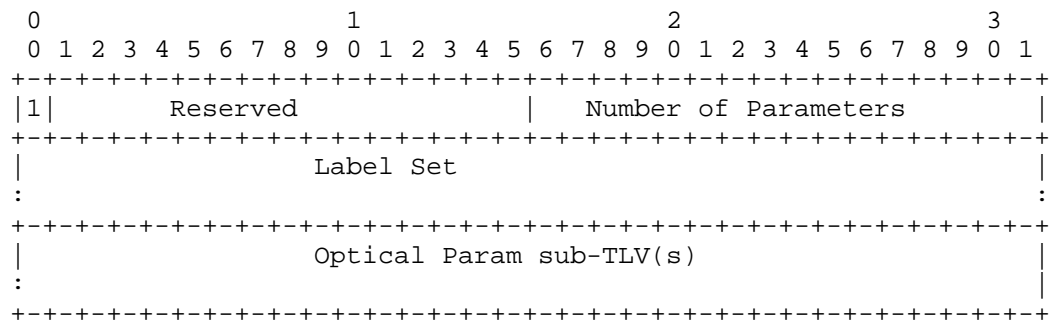
0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1								
0										Reserved										Number of Parameters																			
										Optical Param sub-TLV(s)																													
:																																							

Where:

W = 0. Wavelength Dependency flag. There is no wavelength dependency.

Number of Parameters contained in this vector.

Optical Param sub-TLV(s) present a list of Object as defined in Section 2.1.



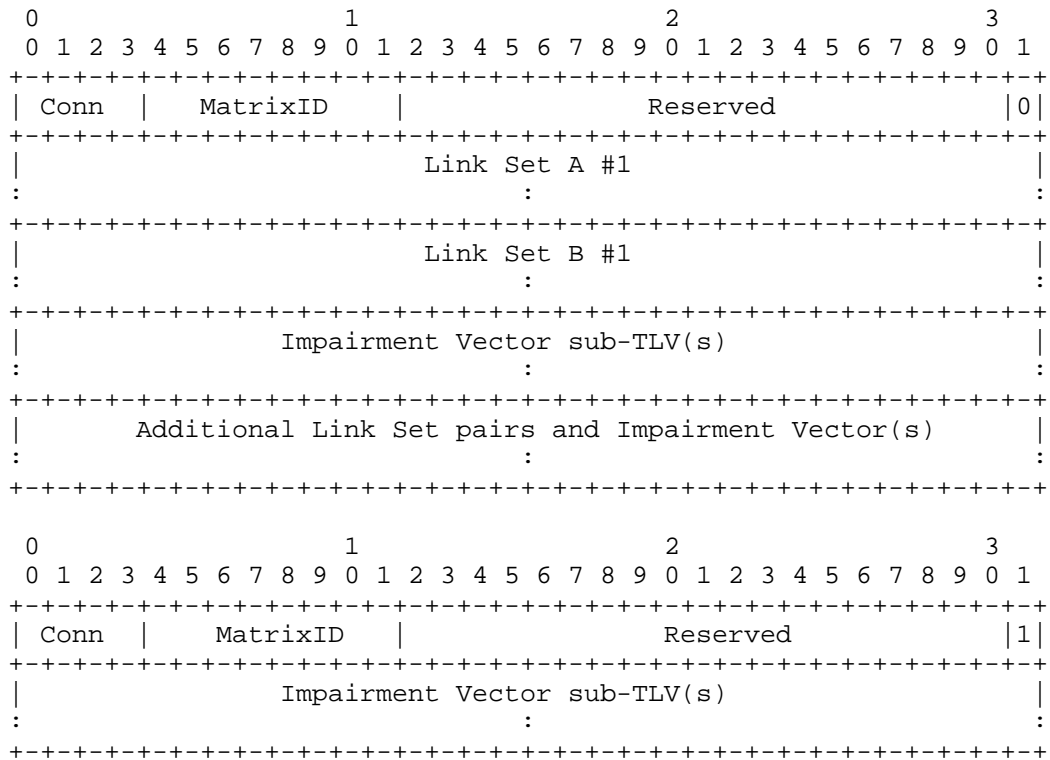
Where:

W = 1. Wavelength Dependency flag. There is wavelength dependency.

The Label Set object is defined in [RFC7579] Section 2.1. Likely an inclusive range will be the only option required by the Action defined in the Label Set.

### 2.3. Impairment Matrix

As defined by the [I-D.ietf-ccamp-wson-iv-info], the impairment matrix follows the same structure as the connectivity matrix.



Where:

Connectivity (Conn) (4 bits) has value 2 for the impairment matrix (Values 0 and 1 defined by [RFC7579]).

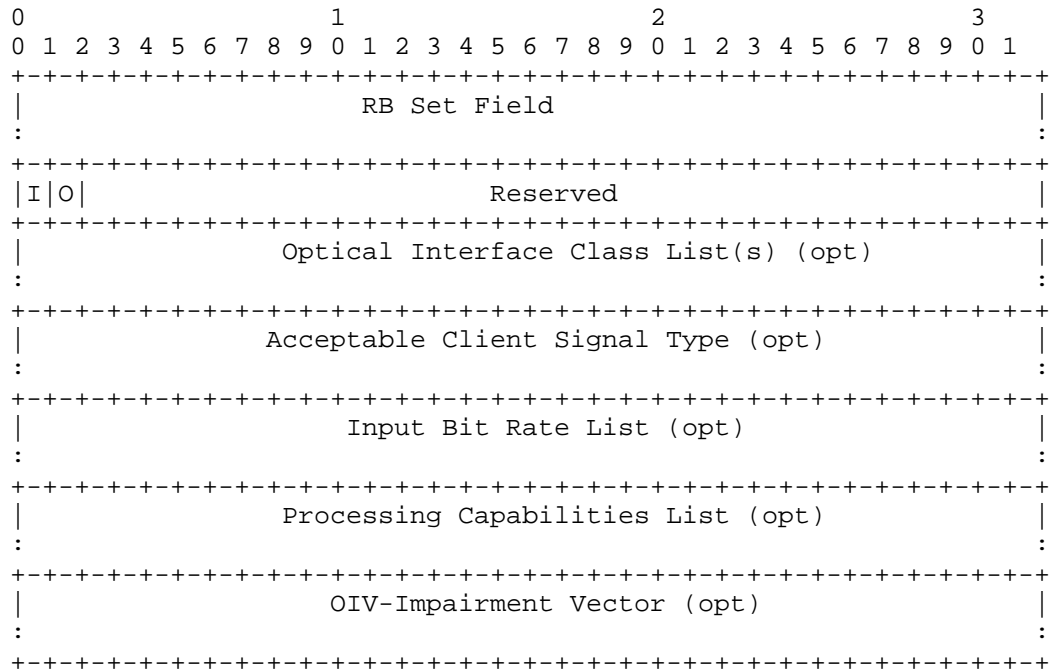
MatrixID: matrix identifier, following same rules as [RFC7579].

N: Node scope flag. With this flag set there's no Link Set information but only a list of optical parameters TLVs that apply to the whole optical node.

The usage of multiple matrixes with connectivity type equal to 2 (Impairment Matrix) MIGHT be used to group optical parameters by connectivity. For example, if a subset of parameters apply to the whole node, a unique matrix with flag N=1 is used. At the same some another subset of parameters applies only to some LinkSet pairs, a specific Impairment Matrix will be added.

## 2.4. Resource Block Information

As defined by [I-D.ietf-ccamp-wson-iv-info], the concept of resource block is extended to support the description of the impairments related to that block. The encoding follows the same structure as the one defined in [RFC7581], with the addition of an optional Impairment Vector sub-object:



The Impairment Vector is defined within Section 2.2. All the other fields are defined within [RFC7581].

## 3. Acknowledgements

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#### 5. IANA Considerations

This document does not contain any IANA request.

#### 6. Security Considerations

This document defines an protocol-neutral encoding for an information model describing impairments in optical networks and it does not introduce any security issues. If such a encoding is put into use within a network it will by its nature contain details of the physical characteristics of an optical network. Such information would need to be protected from intentional or unintentional disclosure.

## 7. References

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- [RFC7579] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "General Network Element Constraint Encoding for GMPLS-Controlled Networks", RFC 7579, DOI 10.17487/RFC7579, June 2015, <<https://www.rfc-editor.org/info/rfc7579>>.

[RFC7581] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, DOI 10.17487/RFC7581, June 2015, <<https://www.rfc-editor.org/info/rfc7581>>.

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GMPLS Routing and Signaling Framework for B100G  
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Abstract

The 2016 revision of G.709 introduces support for OTU links with rates larger than 100G. This document provides a framework to address the GMPLS routing and signalling extensions that enable GMPLS to setup paths through network that contain these newly introduced OTUCn links.

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## 1. Introduction

The current GMPLS routing [RFC7138] and signaling extensions [RFC7139] includes coverage for all the OTN capabilities that were defined in the 2012 version of G.709 [ITU-T\_G709\_2012].

The 2016 version of G.709 [ITU-T\_G709\_2012] introduces support for higher rate OTU signals, termed OTUCn (which have a nominal rate of  $n \times 100$  Gbps). The newly introduced OTUCn represent a very powerful extension to the OTN capabilities, and one which naturally scales to transport any newer clients with bit rates in excess of 100G, as they are introduced.

This document presents an overview of the changes introduced in [ITU-T\_G709\_2016] and analyzes them to identify the extensions that would be required in GMPLS routing and signaling to enable the new OTN capabilities.

### 1.1. Scope

For the purposes of the B100G control plane discussion, the OTN should be considered as a combination of ODU and OTSi layers. Note that [ITU-T\_G709\_2016] is deprecating the use of the term "Och" for B100G entities, and leaving it intact only for maintaining continuity in the description of the signals with bandwidth upto 100G. This document focuses on only the control of the ODU layer. The control of the OTSi layer will be addressed in a separate document.

## 2. Terminology

### 2.1. Requirements Language

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

### 2.2. OTN terminology used in this document

- a. OPUCn: Optical Payload Unit -Cn.
- b. ODUCh: Optical Data Unit - Cn.
- c. OTUCn: Fully standardized Optical Transport Unit - Cn.
- d. OTUCn-M: This signal is an extension of the OTUCn signal introduced above. This signal contains the same amount of overhead as the OTUCn signal, but contains a reduced amount of

payload area. Specifically the payload area consists of M 5G tributary slots (where M is strictly less than  $20 \cdot n$ ).

- e. PSI: OPU Payload structure Indicator. This is a multi-frame message and describes the composition of the OPU signal. This field is a concatenation of the Payload type (PT) and the Multiplex Structure Indicator (MSI) defined below.
- f. MSI: Multiplex Structure Indicator. This structure indicates the grouping of the tributary slots in an OPU payload area to realize a client signal that is multiplexed into an OPU. The individual clients multiplexed into the OPU payload area are distinguished by the Tributary Port number (TPN).
- g. GMP: Generic Mapping Procedure.

Detailed description of these terms can be found in [ITU-T\_G709\_2016].

### 3. Overview of B100G in G.709

This section provides an overview of new features in [ITU-T\_G709\_2016].

#### 3.1. OTUCn

In G.709 [ITU-T\_G709\_2012], the standard mechanism for transporting a client signal is to first map it into an ODU signal (of the appropriate rate), and then switch the resulting ODU signal through the OTN network. In the course of its traversal through the OTN network, the ODU signal generated by the mapper is either (a) multiplexed into higher-order ODU, and then encapsulated to form an OTU or (b) directly encapsulated into an OTU signal that defines the section layer. The option (b), i.e. direct encapsulation into an OTU was possible only for ODU1/ODU2/ODU3/ODU4; ODU signals with other rates (e.g. ODUFlex) would first have to be processed per option (a) above. The term "client signal" is generic in the sense that it encompasses both Constant Bit rate (CBR) clients (e.g. 10GBASE-R, SONET OC-768), or packet traffic -- where the goal is to transfer the payload from end-to-end (without regard for bit transparency at the PCS layer). Given that OTU4 was the highest rate section layer signal supported in [ITU-T\_G709\_2012], the client signal rates were limited to be less than 100G (if ODU-VCAT was not used).

In order to carry client signals with rates greater than 100Gbps, [ITU-T\_G709\_2016] takes a general and scalable approach that decouples the rates of OTU signals from the client rate evolution. The new OTU signal is called OTUCn; this signal is defined to have a

rate of (approximately)  $n \times 100\text{G}$ . The following are the key characteristics of the OTUCn signal:

- a. The OTUCn signal contains one ODUCn, which in turn contains one OPUCn signal. The OTUCn and ODUCn signals perform digital section roles only (see [ITU-T\_G709\_2016]:Section 6.1.1). The OTUCn and ODUCn can be seen as being analogous to the regenerator section, and multiplex section in SDH respectively.
- b. The OTUCn signals can be viewed as being formed by interleaving  $n$  OTUC signals (where are labeled 1, 2, ...,  $n$ ), each of which has the format of a standard OTUk signal without the FEC columns (per [ITU-T\_G709\_2016]:Figure 7-1). The ODUCn, and OPUCn have a similar structure, i.e. they can be seen as being formed by interleaving  $n$  instances of ODUC, OPUC signals (respectively) The OTUC signal contains the ODUC, and OPUC signals, just as in the case of fixed rate OTUs defined in G.709 [ITU-T\_G709\_2016].
- c. Each of the OTUC "slices" have the same overhead (OH) as the standard OTUk signal in G.709 [ITU-T\_G709\_2016]. The combined signal OTUCn has  $n$  instances of OTUC OH, ODUC OH, and OPUC OH.
- d. The OTUC signal has a slightly higher rate compared to the OTU4 signal (without FEC); this is to ensure that the OPUC payload area can carry an ODU4 signal.

### 3.1.1.1. Carrying OTUCn between 3R points

As explained above, within G.709 [ITU-T\_G709\_2016], the OTUCn, ODUCn and OPUCn signal structures are presented in a (physical) interface independent manner, by means of  $n$  OTUC, ODUC and OPUC instances that are marked #1 to # $n$ . Specifically, the definition of the OTUCn signal does not cover aspects such as FEC, modulation formats, etc. These details are defined as part of the adaptation of the OTUCn layer to the optical layer(s). The specific interleaving of OTUC/ODUC/OPUC signals onto the optical signals is interface specific and specified for OTN interfaces with standardized application codes in the interface specific recommendations (G.709.x).

The following scenarios of OTUCn transport need to be considered (see Figure 1):

- a. inter-domain interfaces: These types of interfaces are used for connecting OTN edge nodes to (a) client equipment (e.g. routers) or (b) hand-off points from other OTN networks. ITU-T has standardized the Flexible OTN (FlexO) interfaces to support these functions. Recommendation [ITU-T\_G709.1] specifies a flexible interoperable short-reach OTN interface over which an OTUCn ( $n$

$\geq 1$ ) is transferred, using bonded FlexO interfaces which belong to a FlexO group. The FlexO group supports physical interface bonding, management of the group members, overhead for communication between FlexO peers etc. (these overheads are separate from the GCC0 channel defined over OTUCn). In its current form, Recommendation [ITU-T\_G709.1] is limited to the case of transporting OTUCn signals using n 100G Ethernet PHY(s). The mechanisms for transporting the OTUCn signals over 100G optical interfaces are specified in [ITU-T\_G709.1] and are not repeated here. When the PHY(s) for the emerging set of Ethernet signals, e.g. 200GbE and 400GbE, become available, new recommendations can define the required adaptations.

- b. intra-domain interfaces: In these cases, the OTUCn is transported using a proprietary (vendor specific) encapsulation, FEC etc. In future, it may be possible to transport OTUCn for intra-domain links using future variants of FlexO.

=====

OTUCn signal		
Inter+Domain Interface (IrDI) FlexO (G.709.1)	Intra+Domain Interface (IaDI) FlexO (G.709.x) (Future)	Intra+Domain Interface Proprietary Encap, FEC etc.

=====

Figure 1: OTUCn transport possibilities

It is possible for an OTUCn signal to be transported via multiple hops of lower-layer adaptation (see Figure 2). In this scenario, the OTUCn spans multiple optical paths joined by a FlexO segment. An end-to-end OTUCn LSP needs to be setup after the optical circuits are established. The information about the FlexO interfaces (and group) are configured at the FlexO endpoints, and there is no dynamic setup.

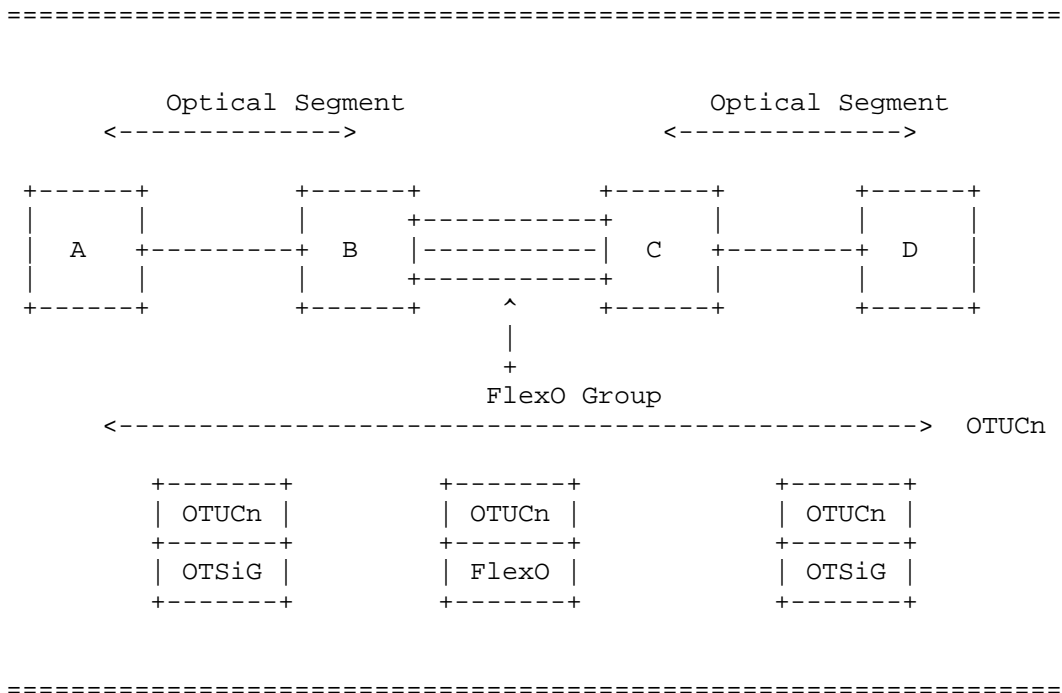


Figure 2: OTUCn transport - Multihop

This document views FlexO (even if there are some digital sub-layers involved in the adaptation) and other OTUCn transport mechanisms as "lower layers", and are therefore considered out-of-scope. The OTUCn layer operates independent of the method used to transport the signal.

### 3.2. ODUCn

The ODUCn signal [ITU-T\_G709\_2016] can be viewed as being formed by the appropriate interleaving of content from n ODUC signal instances. The ODUC frames have the same structure as a standard ODU -- in the sense that it has the same Overhead (OH) area, and the payload area -- but has a higher rate since its payload area can embed an ODU4 signal. The ODUCn signal can be formed in one of the following ways:

By multiplexing lower-rate (i.e. both low-order and high-order) ODUC signals.

Each of the n instances of ODUC can carry the NULL signal (as specified in [ITU-T\_G709\_2016]: Section 17.5.1)



Each of the  $n$  instances of ODUC can carry the PN-11 PRBS test sequence (as specified in [ITU-T\_G709\_2016]: Section 17.5.2)

It is conceivable that vendors might implement proprietary mappings (Payload Type values of 0x80-x8F) of non-OTN client signals. An interoperable control plane cannot make use of these proprietary ODUCn signals, and hence this case isn't considered in this document.

The ODUCn signals have a rate that is captured in Table 1.

ODU Type	ODU Bit Rate
ODUCn	$n \times 239/226 \times 99,532,800 \text{ kbit/s} = n \times 105,258,138.053 \text{ kbit/s}$

Table 1: ODUCn rates

The ODUCn is a multiplex section ODU signal, and is mapped into an OTUCn signal which provides the regenerator section layer. In some scenarios, the ODUCn, and OTUCn signals will be co-terminous, i.e. they will have identical source/sink locations. [ITU-T\_G709\_2016] and [ITU-T\_G872] allow for the ODUCn signal to pass through a digital regenerator node which will terminate the OTUCn layer, but will pass the regenerated (but otherwise untouched) ODUCn towards a different OTUCn interface where a fresh OTUCn layer will be initiated (see Figure 3). In this case, an ODUCn LSP needs to be set up to traverse the 3 OTUCn segments.

Specifically, the OPUCn signal flows through these regenerators unchanged. That is, the set of client signals, their TPNs, trib-slot allocation remains unchanged. Note however that the ODUCn Overhead (OH) might be modified if TCM sub-layers are instantiated in order to monitor the performance of the repeater hops. In this sense, the ODUCn should not be seen as a general ODU which can be switched via an ODUk cross-connect.

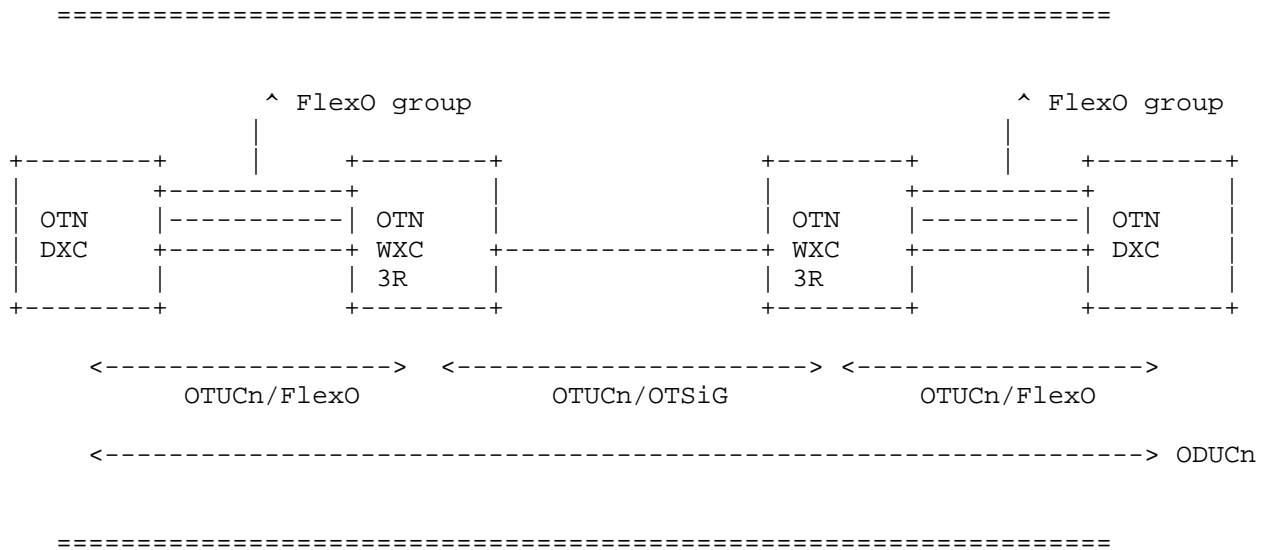


Figure 3: Multi-hop ODUCh signal

### 3.3. OTUCn-M

The standard OTUCn signal has the same rate as that of the ODUCh signal as captured in Table 1. This implies that the OTUCn signal can only be transported over wavelength groups which have a total capacity of multiples of (approximately) 100G. Modern DSPs support a variety of bit rates per wavelength, depending on the reach requirements for the optical link. With this in mind, ITU-T supports the notion of a reduced rate OTUCn signal, termed the OTUCn-M. The OTUCn-M signal is derived from the OTUCn signal by retaining all the  $n$  instances of overhead (one per OTUC slice) and crunching the OPUC tributary slots marked as "unavailable".

### 3.4. OPUCn Time Slot Granularity

[ITU-T\_G709\_2012] introduced the support for 1.25G granular tributary slots in OPU2, OPU3, and OPU4 signals. With the introduction of higher rate signals such as the OPUCn, it is no longer practical for the optical networks (and the datapath hardware) to support a very large number of flows at such a fine granularity. ITU-T has defined the OPUCn with a tributary slot granularity of 5G. This means that the ODUCh signal has  $20*n$  tributary slots (of 5Gbps capacity).

### 3.5. Structure of OPUCn MSI with Payload type 0x22

As mentioned above, the OPUCn signal has  $20 \times n$  5G tributary slots. The OPUCn contains  $n$  PSI structures, one per OPUC instance. The PSI structure consists of the Payload Type (of 0x22), followed by a Reserved Field (1 byte), followed by the MSI. The OPUCn MSI field has a fixed length of  $40 \times n$  bytes and indicates the ODTU content of each TS of an OPUCn. Two bytes are used for each of the  $20 \times n$  tributary slots, and each such information structure has the following format ([ITU-T\_G709\_2016] G.709:Section 20.4.1):

- a. The TS availability bit 1 indicates if the tributary slot is available or unavailable
- b. The TS occupation bit 9 indicates if the tributary slot is allocated or unallocated
- c. The tributary port number in bits 2-8, 10-16 indicates the identity of the OTN client signal (i.e. LO-ODU) that is being transported in this TS; a flexible assignment of tributary port to tributary slots is possible. Note that  $1 \leq \text{TPN} \leq 10 \times n$ . The value is set to all-0s when the occupation bit has the value 0 (tributary slot is unallocated). The same TPN value is used in all the TS(s) assigned to a given OTN client signal.

### 3.6. Client Signal Mappings

Note that [ITU-T\_G709\_2016] introduces support for OTUCn signals with rates of  $n \times 100\text{G}$  and also introduces support for client signals with rates larger than 100G (e.g. the future 400GBASE-R client being standardized by IEEE, higher packet streams from NPUs). The approach taken by the ITU-T to map non-OTN client signals to the appropriate ODU containers is as follows:

- a. All client signals with rates less than 100G are mapped as specified in [ITU-T\_G709\_2016]:Clause 17. These mappings are identical to those specified in the earlier revision of G.709 [ITU-T\_G709\_2012]. Thus, for example, the 100GBASE-X/10GBASE-R signals are mapped to ODU0/ODU2e respectively (see Table 2 -- based on Table 7-2 in [ITU-T\_G709\_2016])
- b. Always map the new and emerging client signals to ODUFlex signals of the appropriate rates (see Table 2 -- based on Table 7-2 in [ITU-T\_G709\_2016])
- c. Drop support for ODU Virtual Concatenation. This simplifies the network, and the supporting hardware since multiple different mappings for the same client are no longer necessary. Note that

legacy implementations that transported sub-100G clients using ODU VCAT shall continue to be supported.

- d. ODUflex signals are low-order signals only. If the ODUflex entities have rates of 100G or less, they can be transported using either an ODU<sub>k</sub> (k=1..4) or an ODUC<sub>n</sub> server layer. On the other hand, ODUflex connections with rates greater than 100G will require the server layer to be ODUC<sub>n</sub>. The ODUC<sub>n</sub> signals must be adapted to an OTUC<sub>n</sub> signal. Figure 4 illustrates the hierarchy of the digital signals defined in [ITU-T\_G709\_2016].

ODU Type	ODU Bit Rate
ODU0	1,244,160 Kbps
ODU1	$239/238 \times 2,488,320$ Kbps
ODU2	$239/237 \times 9,953,280$ Kbps
ODU2e	$239/237 \times 10,312,500$ Kbps
ODU3	$239/236 \times 39,813,120$ Kbps
ODU4	$239/227 \times 99,532,800$ Kbps
ODUflex for CBR client signals	$239/238 \times$ Client signal Bit rate
ODUflex for GFP-F mapped packet traffic	Configured bit rate
ODUflex for IMP mapped packet traffic	$s \times 239/238 \times 5\,156\,250$ kbit/s: $s=2,8,5*n$ , $n \geq 1$
ODUflex for FlexE aware transport	$103\,125\,000 \times 240/238 \times n/20$ kbit/s, where n is total number of available tributary slots among all PHYs which have been crunched and combined.

Note that this table doesn't include ODUC<sub>n</sub> -- since it cannot be generated by mapping a non-OTN signal. An ODUC<sub>n</sub> is always formed by multiplexing multiple LO-ODUs.

Table 2: Types and rates of ODUs usable for client mappings

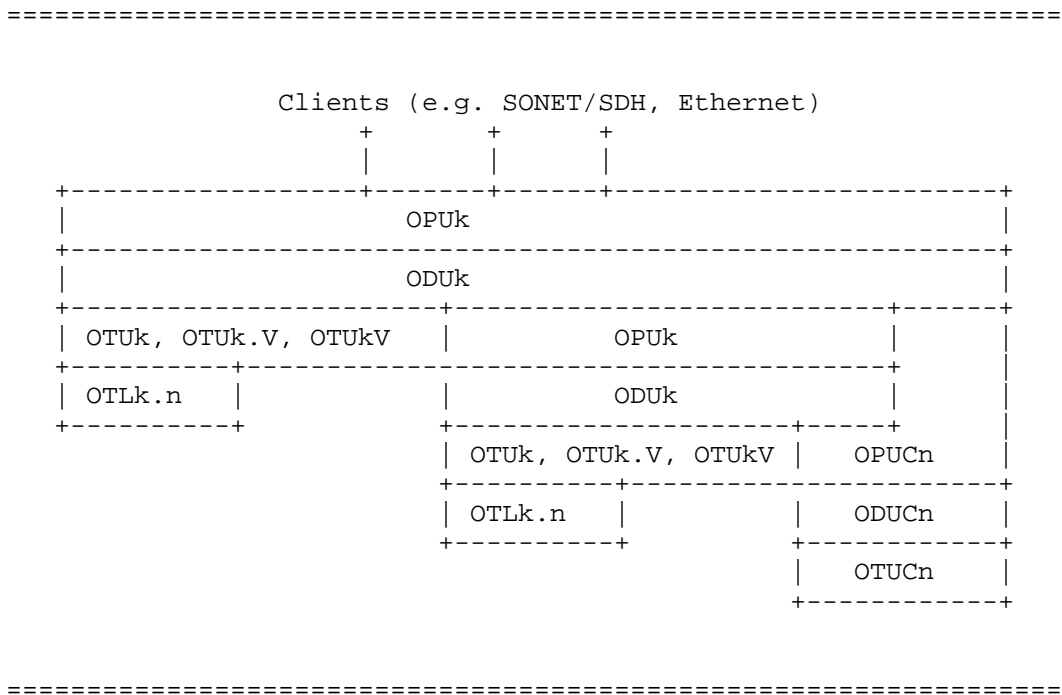


Figure 4: Digital Structure of OTN interfaces (from G.709:Figure 6-1)

#### 4. Usecases

This section introduces various usecases that provide the rationale for the requirements that any solution must satisfy. At a later point in time, it is possible to consolidate these usecases so that all the multiplexing (and demultiplexing) variants are encountered along the path of an end-to-end ODU circuit.

Note-1: These usecases present scenarios in which OTUCn links are depicted. These illustrations do not highlight how the OTUCn is transported between the 3R points. That is, these usecases cover cases in which a standard FlexO interface (e.g. as defined in [ITU-T\_G709.1]) is used, or whether a vendor specific mapping of OTUCn to OTSiG (as defined in [ITU-T\_G872]) is used. In other words, multiple variants of these usecases based on FlexO usage (or not) are not included in this document.

Note-2: This version of the document covers many usecases in detail. Future versions of this document may combine multiple usecases (e.g. all cases involving ODUflex into one broad category), and retain only the minimal set of usecases.

#### 4.1. 100GE Client Service with a homogeneous chain of OTUC1 links

In the scenario illustrated in Figure 5 a 100GBASE-R client is mapped into an ODU4 at NE1. The resulting ODU4 signal is multiplexed into the ODU4 server layer (using GMP) and further encapsulated to form the OTUC1 signal. The links NE1-NE2, and NE2-NE3 are both OTUC1 links -- and they can carry one 100GE client mapped into an ODU4 server layer. Actions performed at NE2 are: (a) terminate OTUC1, and ODU4 towards NE1 (b) demultiplex the ODU4 signal from ODU4 (c) map the ODU4 signal onto a different ODU4/OTUC1 towards NE3. NE3 performs the inverse sequence of steps performed at NE1, and recovers the 100GBASE-R client from the ODU4 signal. Note that the ODU4 and ODU4 signals are not "interoperable" and that the ODU4 is a server layer to the ODU4 signal.

This illustration is also applicable to the usecase in which members of a FlexE group are transported in a flexe-unaware mode in the transport network. Although this illustration included only OTUC1 signals, any higher rate OTUCn signal can be substituted for these signals. In this particular scenario, there are two adjacent ODU4 hops, and the NE2 demultiplexes (and multiplexes) the ODU4 onto the ODU4. It is possible to construct an alternative scenario in the case when NE2 acts as a regenerator, and doesn't terminate the ODU4 signals in the two hops, and instead repeats the ODU4 signal; this scenario is specifically discussed in Section 4.6.

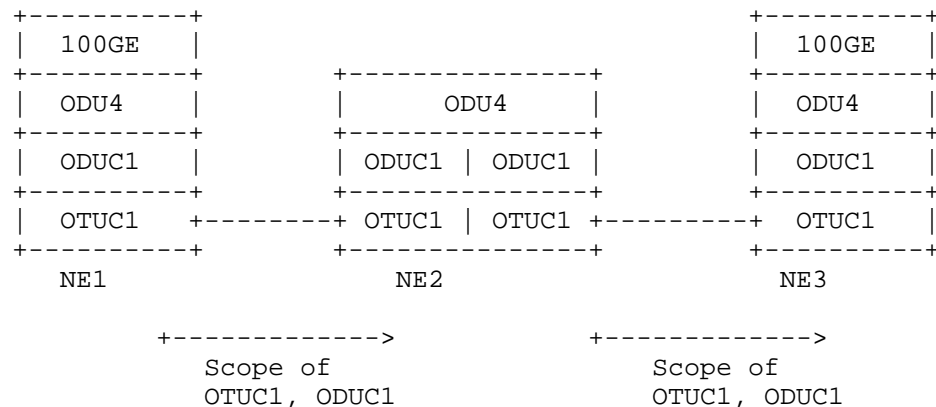


Figure 5: 100GE Client service

#### 4.2. 100GE Client Service with a mix of OTU4, and OTUC1 links

In the scenario illustrated in Figure 6 a 100GBASE-R client is mapped into an ODU4 at NE1. The resulting ODU4 signal is encapsulated with an OTU layer to form the OTU4 signal. Actions performed at NE2 are: (a) terminate OTU4 layer, and extract the ODU4 signal (b) map the ODU4 signal onto a different ODUc1/OTUc1 towards NE3. NE3 performs the same set of actions that were performed by NE3 in Figure 5. This usecase illustrates a scenario in which an ODU4 signal can span between network elements regardless of whether they support the OTUcN interfaces or not.

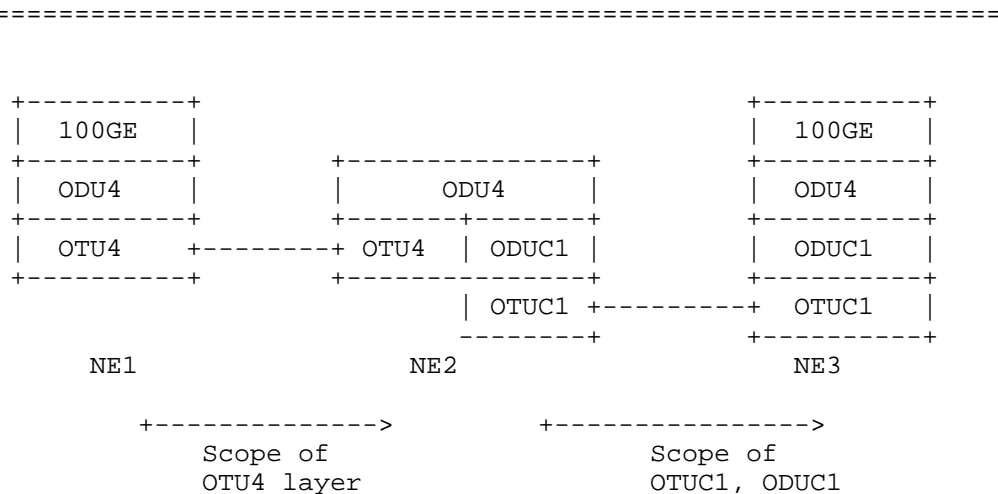


Figure 6: 100GE Client Service with a mix of OTU4, and OTUC1 links

### 4.3. 400GE Client Service with a mix of OTUCn links

In the scenario illustrated in Figure 7 a 400GBASE-R client is mapped into an ODUflex at NE1. The resulting ODUflex signal is multiplexed into an ODU4 (using GMP), and then transformed into an OTUC4 signal. The links between NE1-NE2, and NE2-NE3 are OTUC4 and OTUC6 (respectively). Actions performed at NE2 are: (a) terminate OTUC4, and ODU4 towards NE1 (b) demultiplex the ODUflex signal from ODU4 (c) map the ODUflex signal onto ODU6/OTUC6 towards NE3. NE3 performs the inverse sequence of steps performed at NE1, and recovers the 400GBASE-R client from the ODUflex signal.

Although not specifically illustrated in this figure, the 200G of spare capacity in the NE2-NE3 links can be used to carry other client signals.. Although the scenario illustrated in Figure 7 is specific to 400GE, the treatment for packet clients at other rates (e.g. 25G, 50G, 200G) follows a very similar processing sequence. In the case of 25GBASE-R clients, the 25GE client signal will be mapped to an ODUflex, and can be multiplexed into an ODU4 signal, or an ODUCn signal as illustrated here.

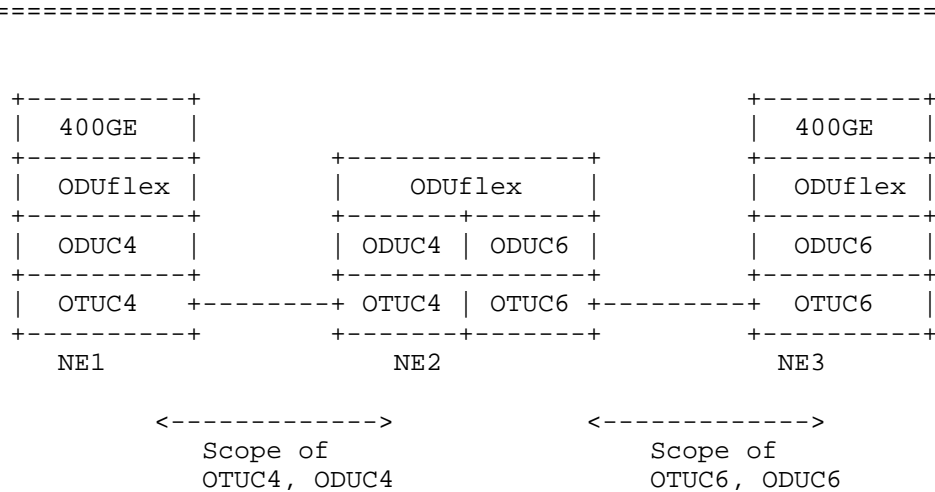


Figure 7: 400GE transport over OTUCn links

#### 4.4. FlexE aware transport over OTUCn links

In the scenario illustrated in Figure 8 NE1 interfaces to a client equipment which includes the FlexE SHIM functions which originate/terminate a FlexE group. The transport network edge node NE2 is FlexE aware -- but doesn't terminate the FlexE group. NE1 may (as defined in the FlexE draft [I-D.izh-ccamp-flex-e-fwk]), crunch the unavailable tributary slots in the FlexE PHY signals, and map the resultant stream to one or more ODUflex signals. The links between NE1-NE2, and NE2-NE3 are OTUC4 and OTUC6 (respectively). Actions performed at NE2 are: (a) terminate OTUC4, and ODUC4 towards NE1 (b) demultiplex the ODUflex signal from ODUC4 (c) map the ODUflex signal onto ODUC6/OTUC6 towards NE3. NE3 recovers the Crunched and combined PHY(s) from the ODUflex signal, re-adds the unavailable calendar slots, and outputs the resulting stream towards the FlexE PHY(s).



In the scenario illustrated in Figure 8 the lowest rate OTUCn link is the OTUC4 link between NE1-NE2. This means that the size of the FlexE group is at most 4. FlexE groups with greater sizes can be handled by utilizing appropriate OTUCn links. Note that at most 400G of the capacity of OTUC6 (or 600G) NE2-NE3 link is occupied by the ODUflex signal; the remaining bandwidth can be allocated to other client signals.

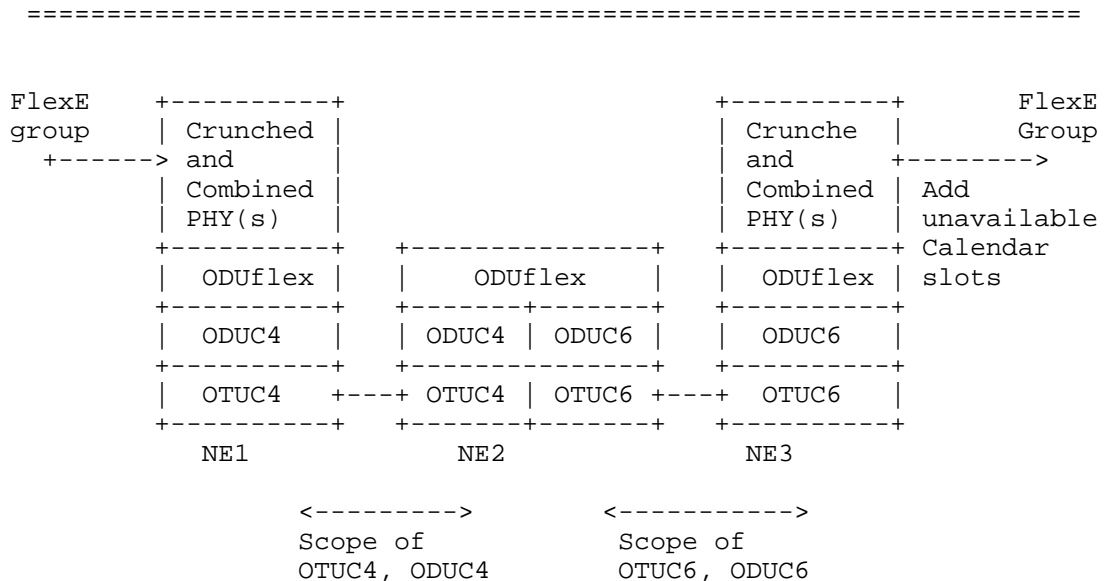


Figure 8: FlexE aware transport over OTUCn links

#### 4.5. FlexE Client transport over OTUCn links

This use case (see Figure 9) concerns the scenario in which a FlexE group is terminated at the transport network edge node (via the FlexE SHIM function), and the FlexE clients are demultiplexed, and independently transported through the OTN network. In the scenario illustrated in Figure 9 the lowest rate OTUCn link is the OTUC4 link between NE1-NE2. This means that the maximum bit rate of the FlexE client is at most 400G. FlexE clients with greater sizes can be handled by utilizing appropriate OTUCn links. This figure illustrates the case in which one FlexE client is transported between NE1 and NE3. Other FlexE clients recovered at NE1 can be routed independently to NE3, or to other network elements.

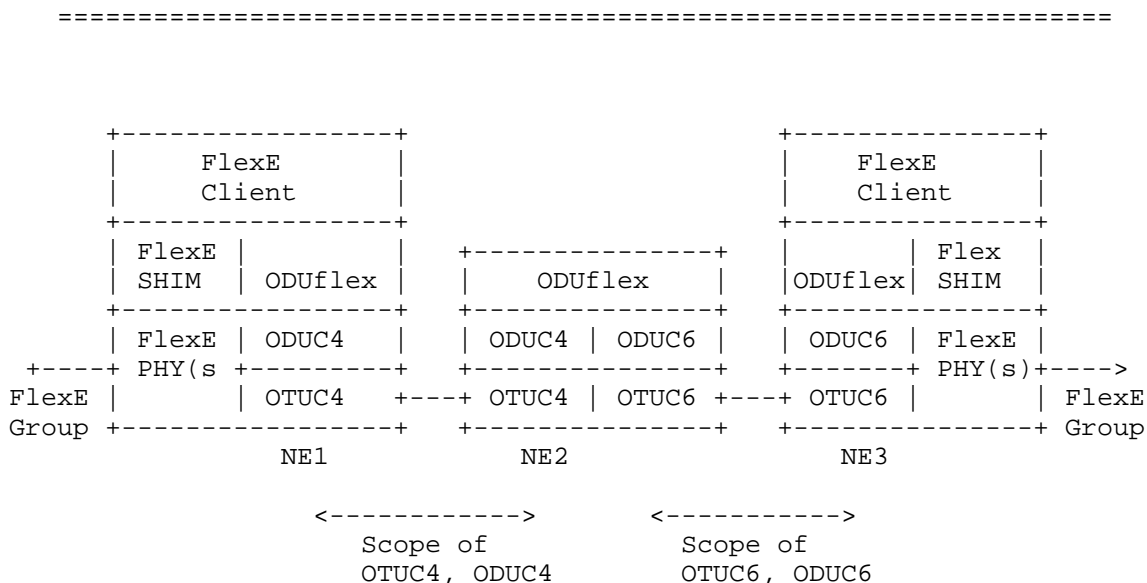


Figure 9: FlexE client transport over OTUCn links

#### 4.6. Multihop ODUCn link

As mentioned in the introductory section, the ODUCh is not a switchable entity. The ODUCh layer is a server layer, which more-or-less occupies the position of a section layer in OTN networks. As such, the ODUCh signal must be terminated and the contained low-order ODU flows can be switched independently to other OTN interfaces. G.709 and G.872 however allow for digital regenerators to terminate the OTUCh layer, and reinject the ODUCh layer towards another interface (where a new OTUCh section layer is started). This scenario is illustrated in Figure 10. In this figure, NE3 is the regenerator. The ODU2 signal is terminated at NE2, and NE4. At the regeneration points, all the clients embedded inside the ODUCh signal are not touched (i.e. no TS changes can occur). More specifically, the OPUC2 signal is not modified in any way. However, the ODU2 OH may be modified if intrusive TCM monitoring points are applied to the ODU2 signal at NE3. It is for this reason that the ODU2 entity must be visible at NE3.

In scenarios involving multi-hop ODUCh links, GMPLS signalling will be required to setup multiple ODUCh LSPs, each covering a regenerator section (since an end-to-end ODUCh LSP is not possible except in very

simple configurations). A LO-ODU can then be switched across multiple ODUCn LSPs (possibly with different rates).

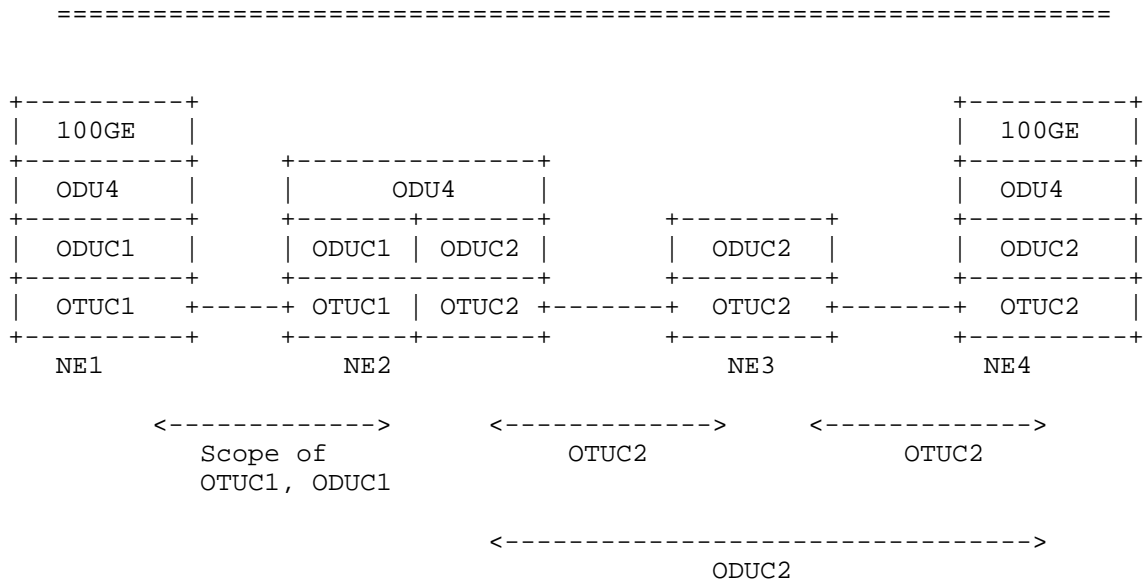


Figure 10: Multihop ODUCn link

#### 4.7. Use of OTUCn-M links

The scenario illustrated in Figure 11 is a variant of the basic usecase presented in Figure 5. The only difference is that the second hop of the ODU4 connection makes use of a OTUC2-30 link which has a capacity of 150G.

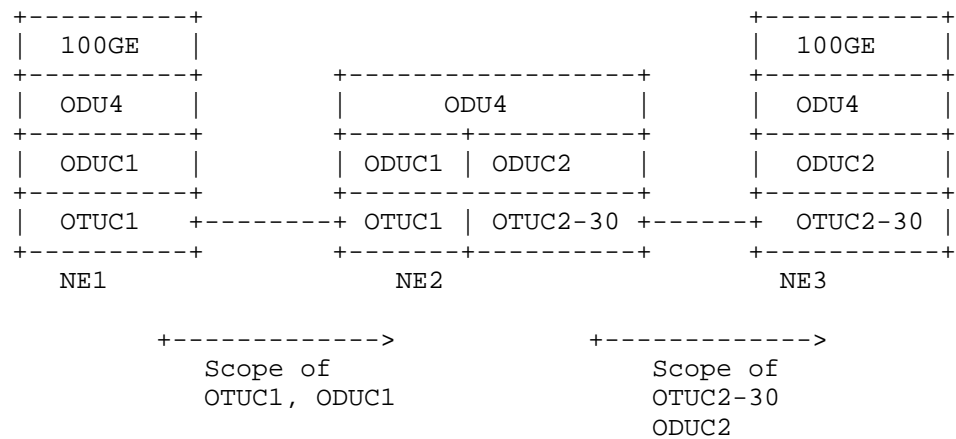


Figure 11: 100GE Client service over OTUCn-M links

#### 4.8. Intermediate State of ODU mux

The ODUCn links have a tributary slot granularity of 5G -- and this makes it a bit inefficient if a small number of ODU0 flows have to be switched across an ODUCn links. In these cases, it is conceivable that the intermediate nodes may offer the convenience of a intermediate-stage multiplexing, whereby multiple ODU0 flows are first multiplexed into a higher rate container (e.g. ODU2), and then multiplexed into an ODUCn signal. This however assumes that all these ODU0 flows are co-routed in the network. If this assumption cannot be made, the only solution is to multiplex these ODU0 flows into higher rate flows, from the source of the traffic. This usecase isn't elaborated in this document. We can add details if required.

### 5. GMPLS Implications

#### 5.1. OTN ODUCn/OTUCn hierarchy

As described in [ITU-T\_G872], the digital layers of the OTN are divided into the OTU layer and a hierarchy of one or more ODU layers. As an ODUCn cannot be used to support non-OTN client signals, the OTN client signals (e.g. ODU0, ODU1, ODU2, ODU2e, ODU3, ODU4, ODUflex) are first multiplexed into an ODUCn container, then the ODUCn

container is then mapped into OTUCn (see Figure 1). The signal hierarchy supported by the ODUCn and OTUCn needs to be taken into consideration in control plane Routing and Signaling.

ODUCn based connection management is concerned with controlling the connectivity of ODUCn paths. According to [ITU-T\_G872], the intermediate nodes with ODUCn do not support the switching of ODUCn tributary slot. Intermediate ODUCn points are only considered as a forwarding node. Once an ODUCn path is used to transport client signal, the TS occupied will not change across the ODUCn network.

## 5.2. Implications for GMPLS Signaling

[RFC7139] extends the base RSVP-TE signaling specification [RFC4328] to define RSVP-TE signaling extensions that can be used to control OTN networks built in accordance with [ITU-T\_G709\_2012]. [ITU-T\_G709\_2016] introduced some new containers, such as OPUCn, ODUCn, and OTUCn. The mechanisms defined in [RFC7139] do not support these new OTN features. Therefore, GMPLS signaling protocols MUST be extended to support this new functionality. The following summarizes key aspects that should be considered for GMPLS signaling extensions:

- a. Per the description in clause 7 of [ITU-T\_G872], "the digital layers of the OTN are divided into the OTU layer and a hierarchy of one or more ODU layers". In B100G links, the ODUCn layer is the bottom of the ODU hierarchy, and an ODUCn (induced) LSP needs to be established before the LO-ODUs can flow across this link. The traffic parameters in a signaling message should be extended to support the new signal type(s) for the ODUCn signals. This approach keeps the treatment for ODUCn signals consistent with that of other ODU(s).
- b. Support the new TS granularity: the signaling protocol should be able to identify the TS granularity (i.e., the new 5 Gbps TS granularity) to be used for establishing a Hierarchical LSP that will be used to carry service LSP(s) requiring a specific TS granularity.
- c. Support for LSP setup of new ODUCn containers with related mapping and multiplexing capabilities.
- d. A new label format MUST carry the information about the set of ODUCn tributary slots allocated to a specific LO-ODU. It MUST be possible for a single LO-ODU to occupy an arbitrary set of tributary slots, selected from one or more OTUC/ODUC instances.
- e. Support for TPN allocation and negotiation: TPN needs to be configured as part of the MSI information. A signaling mechanism

must be identified to carry TPN information if the control plane is used to configure MSI information. The range of TPN is  $[1..10*n]$  and the range of TPN is smaller than the number of tributary slots ( $20*n$ ); e.g. it is not possible to carry 15 5G ODUflex signals in an ODUC1. This constraint MUST be taken into account in the control plane supported).

- f. Support for LSP setup of OTUCn sub rates (OTUCn-M) path: based on previous extensions, there should be new signal mechanism to declare the OTUCn-m information. The GMPLS signalling protocol SHALL support the setup of OTUCn sub rates (OTUCn-M) LSP, which includes the negotiation of unavailable slots number, slots position and allocation of slot resources.
- g. The GMPLS signalling protocol should be able to specify the new ODUCn/OTUCn signal types and related traffic information. The traffic parameters should be extended in a signalling message to support the new ODUCn/OTUCn signal types

### 5.3. Implications for GMPLS Routing

The path computation process needs to select a suitable route for an ODUCn/OTUCn/OTUCn-M connection request. In order to perform the path computation, it needs to evaluate the available bandwidth/slots available on one or more candidate links. The routing protocol SHOULD be extended to carry sufficient information to represent ODU Traffic Engineering (TE) topology.

The Interface Switching Capability Descriptors defined in [RFC4203] present a new constraint for LSP path computation. [RFC4203] defines the Switching Capability, related Maximum LSP Bandwidth, and Switching Capability specific information. [RFC7138] updates the ISCD to support ODU4, ODU2e and ODUflex. The new Switching Capability specific information provided in [RFC7138] have to be adapted to support new features contained in [G709-2016]. The following requirements should be considered:

- a. Support for carrying the link multiplexing capability: As discussed in Section 3.1.2, many different types of low-order ODU(s) (e.g. ODUflex, ODU4) can be multiplexed into the ODUCn. An ODUCn path may support one or more types of ODUk signals. The routing protocol should be capable of carrying this multiplexing capability.
- b. Support for advertising 5G Tributary Slot Granularity introduced [ITU-T\_G709\_2016].

- c. Support for advertisement of available bandwidth in an ODUCn path.

## 6. Open Issues

- 1. [Note (RSV)]: This document elaborates on several FlexE and 400GE usecases. Since all these cases map the non-OTN client signals into ODUFlex signals of various rates, it might be better to combine all these usecases into one category that handles ODUFlex LSPs. From a control plane point of view, the differences in the data plane processing are not relevant. This change will be made in a future revision of this document (if there is agreement).

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## 10. IANA Considerations

This memo includes no request to IANA.

## 11. Security Considerations

None.

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GMPLS Routing and Signaling Framework for B100G  
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Abstract

This document provides a framework to describe how to use current existing GMPLS routing and signaling to set up ODUk/ODUflex over ODUCh link, as a result of the support of OTU/ODU links with rates larger than 100G in the 2016 version of G.709.

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## 1. Introduction

The current GMPLS routing [RFC7138] and signaling extensions [RFC7139] includes coverage for all the OTN capabilities that were defined in the 2012 version of G.709 [ITU-T\_G709\_2012].

The 2016 version of G.709 [ITU-T\_G709\_2016] introduces support for higher rate OTU signals, termed OTUCn (which have a nominal rate of  $n \times 100$  Gbps). How to set up ODUk/ODUflex over ODUCn link is still an unresolved issue, which is not covered in any draft in IETF. This document presents an overview of the changes introduced in

[ITU-T\_G709\_2016] that bring impact to this topic and analyzes them to identify the extensions that would be required in GMPLS routing and signaling to enable the setup of ODUk/ODUflex over ODUCn.

### 1.1. Scope

For the purposes of the B100G control plane discussion, the OTN should be considered as a combination of ODU and OTSi layers. Note that [ITU-T\_G709\_2016] is deprecating the use of the term "OCh" for B100G entities, and leaving it intact only for maintaining continuity in the description of the signals with bandwidth upto 100G. This document focuses on only the control of the ODU layer. The control of the OTSi layer is out of scope of this document. But in order to facilitate the description of the challenges brought by [ITU-T\_G709\_2016] to B100G GMPLS routing and signalling, some general description about OTSi will be discussed in this draft.

## 2. Terminology

### 2.1. Requirements Language

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

### 2.2. OTN terminology used in this document

- a. OPUCn: Optical Payload Unit -Cn.
- b. ODUCn: Optical Data Unit - Cn.
- c. OTUCn: Fully standardized Optical Transport Unit - Cn.
- d. OTUCn-M: This signal is an extension of the OTUCn signal introduced above. This signal contains the same amount of overhead as the OTUCn signal, but contains a reduced amount of payload area. Specifically the payload area consists of M 5G tributary slots (where M is strictly less than 20\*n).
- e. PSI: OPU Payload structure Indicator. This is a multi-frame message and describes the composition of the OPU signal. This field is a concatenation of the Payload type (PT) and the Multiplex Structure Indicator (MSI) defined below.
- f. MSI: Multiplex Structure Indicator. This structure indicates the grouping of the tributary slots in an OPU payload area to realize a client signal that is multiplexed into an OPU. The individual

clients multiplexed into the OPU payload area are distinguished by the Tributary Port number (TPN).

- g. GMP: Generic Mapping Procedure.
- h. OTSiG: see [ITU-T\_G872]
- i. OTSiA: see [ITU-T\_G872]

Detailed description of these terms can be found in [ITU-T\_G709\_2016].

### 3. Overview of B100G in G.709

This section provides an overview of new features in [ITU-T\_G709\_2016].

#### 3.1. OTUCn

In order to carry client signals with rates greater than 100Gbps, [ITU-T\_G709\_2016] takes a general and scalable approach that decouples the rates of OTU signals from the client rate evolution. The new OTU signal is called OTUCn; this signal is defined to have a rate of (approximately)  $n \times 100\text{G}$ . The following are the key characteristics of the OTUCn signal:

- a. The OTUCn signal contains one ODUCn. The OTUCn and ODUCn signals perform digital section roles only (see [ITU-T\_G709\_2016]:Section 6.1.1)
- b. The OTUCn signals can be viewed as being formed by interleaving  $n$  OTUC signals (where are labeled 1, 2, ...,  $n$ ), each of which has the format of a standard OTUk signal without the FEC columns (per [ITU-T\_G709\_2016]Figure 7-1). The ODUCn have a similar structure, i.e. they can be seen as being formed by interleaving  $n$  instances of ODUC signals (respectively). The OTUC signal contains the ODUC signals, just as in the case of fixed rate OTUs defined in G.709 [ITU-T\_G709\_2016].
- c. Each of the OTUC "slices" have the same overhead (OH) as the standard OTUk signal in G.709 [ITU-T\_G709\_2016]. The combined signal OTUCn has  $n$  instances of OTUC OH, ODUC OH.
- d. The OTUC signal has a slightly higher rate compared to the OTU4 signal (without FEC); this is to ensure that the OPUC payload area can carry an ODU4 signal.

### 3.1.1.1. Carrying OTUCn between 3R points

As explained above, within G.709 [ITU-T\_G709\_2016], the OTUCn, ODUCn and OPUCn signal structures are presented in a (physical) interface independent manner, by means of n OTUC, ODUC and OPUC instances that are marked #1 to #n. Specifically, the definition of the OTUCn signal does not cover aspects such as FEC, modulation formats, etc. These details are defined as part of the adaptation of the OTUCn layer to the optical layer(s). The specific interleaving of OTUC/ODUC/OPUC signals onto the optical signals is interface specific and specified for OTN interfaces with standardized application codes in the interface specific recommendations (G.709.x).

The following scenarios of OTUCn transport need to be considered (see Figure 1):

- a. inter-domain interfaces: These types of interfaces are used for connecting OTN edge nodes to (a) client equipment (e.g. routers) or (b) hand-off points from other OTN networks. ITU-T has standardized the Flexible OTN (FlexO) interfaces to support these functions. Recommendation [ITU-T\_G709.1] specifies a flexible interoperable short-reach OTN interface over which an OTUCn (n >=1) is transferred, using bonded FlexO interfaces which belong to a FlexO group. The FlexO group supports physical interface bonding, management of the group members, overhead for communication between FlexO peers etc. (these overheads are separate from the GCC0 channel defined over OTUCn). In its current form, Recommendation [ITU-T\_G709.1] is limited to the case of transporting OTUCn signals using n 100G Ethernet PHY(s). The mechanisms for transporting the OTUCn signals over 100G optical interfaces are specified in [ITU-T\_G709.1] and are not repeated here. When the PHY(s) for the emerging set of Ethernet signals, e.g. 200GbE and 400GbE, become available, new recommendations can define the required adaptations.
- b. intra-domain interfaces: In these cases, the OTUCn is transported using a proprietary (vendor specific) encapsulation, FEC etc. In future, it may be possible to transport OTUCn for intra-domain links using future variants of FlexO.



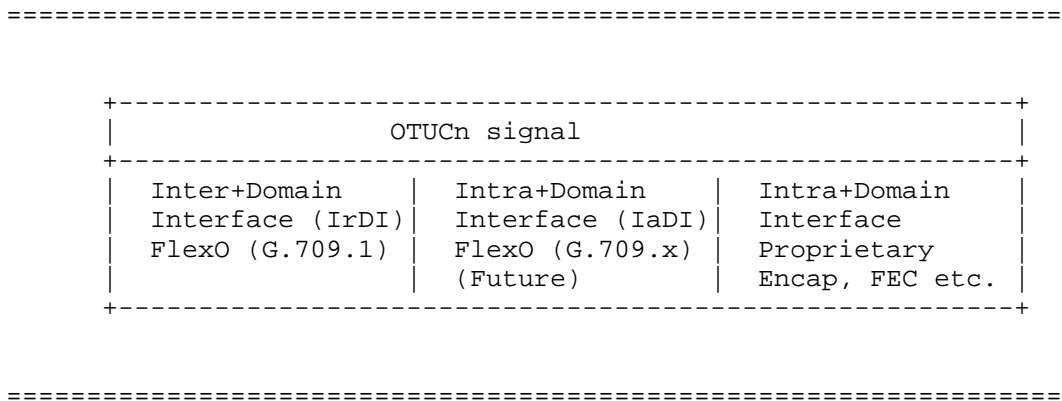


Figure 1: OTUCn transport possibilities

### 3.2. ODUc

The ODUc signal [ITU-T\_G709\_2016] can be viewed as being formed by the appropriate interleaving of content from n ODU signal instances. The ODU frames have the same structure as a standard ODU -- in the sense that it has the same Overhead (OH) area, and the payload area -- but has a higher rate since its payload area can embed an ODU4 signal.

The ODUc signals have a rate that is captured in Table 1.

ODU Type	ODU Bit Rate
ODUc	$n \times 239/226 \times 99,532,800 \text{ kbit/s} = n \times 105,258,138.053 \text{ kbit/s}$

Table 1: ODUc rates

The ODUc is a multiplex section ODU signal, and is mapped into an OTUCn signal which provides the regenerator section layer. In some scenarios, the ODUc, and OTUCn signals will be co-terminous, i.e. they will have identical source/sink locations. [ITU-T\_G709\_2016] and [ITU-T\_G872] allow for the ODUc signal to pass through a digital regenerator node which will terminate the OTUCn layer, but will pass the regenerated (but otherwise untouched) ODUc towards a different OTUCn interface where a fresh OTUCn layer will be initiated (see Figure 2). In this case, the ODUc is carried by 3 OTUCn segments.

Specifically, the OPUCn signal flows through these regenerators unchanged. That is, the set of client signals, their TPNs, trib-slot allocation remains unchanged. Note however that the ODUCn Overhead (OH) might be modified if TCM sub-layers are instantiated in order to monitor the performance of the repeater hops. In this sense, the ODUCn should not be seen as a general ODU which can be switched via an ODUk cross-connect.

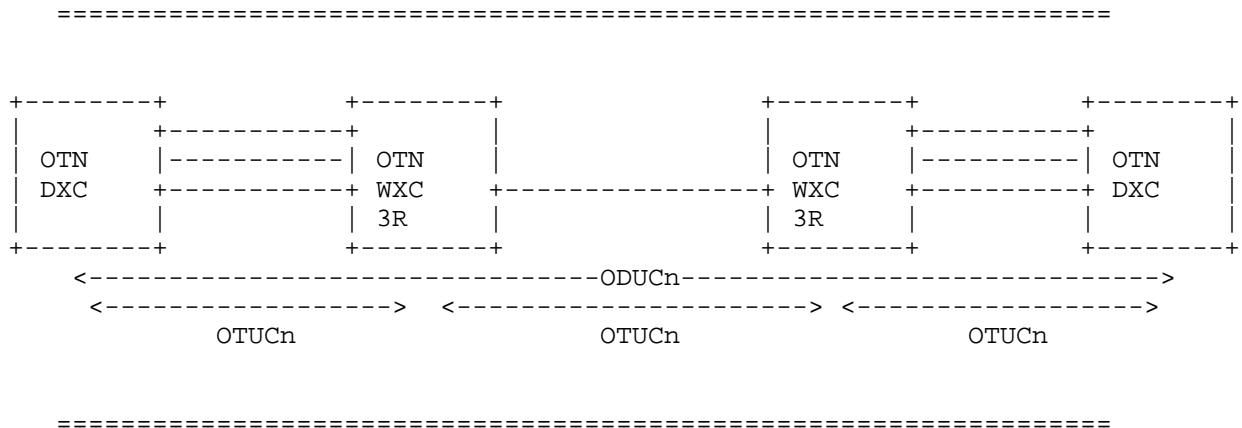


Figure 2: ODUCn signal

### 3.3. OTUCn-M

The standard OTUCn signal has the same rate as that of the ODUCn signal as captured in Table 1. This implies that the OTUCn signal can only be transported over wavelength groups which have a total capacity of multiples of (approximately) 100G. Modern DSPs support a variety of bit rates per wavelength, depending on the reach requirements for the optical link. With this in mind, ITU-T supports the notion of a reduced rate OTUCn signal, termed the OTUCn-M. The OTUCn-M signal is derived from the OTUCn signal by retaining all the  $n$  instances of overhead (one per OTUC slice) but only  $M$  tributary slots of capacity.

### 3.4. Time Slot Granularity

[ITU-T\_G709\_2012] introduced the support for 1.25G granular tributary slots in OPU2, OPU3, and OPU4 signals. With the introduction of higher rate signals, it is no longer practical for the optical networks (and the datapath hardware) to support a very large number of flows at such a fine granularity. ITU-T has defined the OPUC with a tributary slot granularity of 5G. This means that the ODUCn signal has  $20*n$  tributary slots (of 5Gbps capacity).

### 3.5. Structure of OPUCn MSI with Payload type 0x22

As mentioned above, the OPUCn signal has  $20 \times n$  5G tributary slots. The OPUCn contains  $n$  PSI structures, one per OPUC instance. The PSI structure consists of the Payload Type (of 0x22), followed by a Reserved Field (1 byte), followed by the MSI. The OPUCn MSI field has a fixed length of  $40 \times n$  bytes and indicates the availability of each TS. Two bytes are used for each of the  $20 \times n$  tributary slots, and each such information structure has the following format ([ITU-T\_G709\_2016] G.709:Section 20.4.1):

- a. The TS availability bit 1 indicates if the tributary slot is available or unavailable
- b. The TS occupation bit 9 indicates if the tributary slot is allocated or unallocated
- c. b.c. The tributary port # in bits 2 to 8 and 10 to 16 indicates the port number of a specific TS that is allocated to the client; a flexible assignment of tributary port to tributary slots is possible. Numbering of tributary ports are is from 1 to  $10n$ .

### 3.6. Client Signal Mappings

The approach taken by the ITU-T to map non-OTN client signals to the appropriate ODU containers is as follows:

- a. All client signals with rates less than 100G are mapped as specified in [ITU-T\_G709\_2016]:Clause 17. These mappings are identical to those specified in the earlier revision of G.709 [ITU-T\_G709\_2012]. Thus, for example, the 100GBASE-X/10GBASE-R signals are mapped to ODU0/ODU2e respectively (see Table 2 -- based on Table 7-2 in [ITU-T\_G709\_2016])
- b. Always map the new and emerging client signals to ODUFlex signals of the appropriate rates (see Table 2 -- based on Table 7-2 in [ITU-T\_G709\_2016])
- c. Drop support for ODU Virtual Concatenation. This simplifies the network, and the supporting hardware since multiple different mappings for the same client are no longer necessary. Note that legacy implementations that transported sub-100G clients using ODU VCAT shall continue to be supported.
- d. ODUFlex signals are low-order signals only. If the ODUFlex entities have rates of 100G or less, they can be transported using either an ODU $k$  ( $k=1..4$ ) or an ODUC $n$  server layer. On the other hand, ODUFlex connections with rates greater than 100G will

require the server layer to be ODUCn. The ODUCn signals must be adapted to an OTUCn signal. Figure 3 illustrates the hierarchy of the digital signals defined in [ITU-T\_G709\_2016].

ODU Type	ODU Bit Rate
ODU0	1,244,160 Kbps
ODU1	$239/238 \times 2,488,320$ Kbps
ODU2	$239/237 \times 9,953,280$ Kbps
ODU2e	$239/237 \times 10,312,500$ Kbps
ODU3	$239/236 \times 39,813,120$ Kbps
ODU4	$239/227 \times 99,532,800$ Kbps
ODUflex for CBR client signals	$239/238 \times$ Client signal Bit rate
ODUflex for GFP-F mapped packet traffic	Configured bit rate
ODUflex for IMP mapped packet traffic	$s \times 239/238 \times 5\,156\,250$ kbit/s: $s=2,8,5*n$ , $n \geq 1$
ODUflex for FlexE aware transport	$103\,125\,000 \times 240/238 \times n/20$ kbit/s, where n is total number of available tributary slots among all PHYs which have been crunched and combined.

Note that this table doesn't include ODUCn -- since it cannot be generated by mapping a non-OTN signal. An ODUCn is always formed by multiplexing multiple LO-ODUs.

Table 2: Types and rates of ODUs usable for client mappings

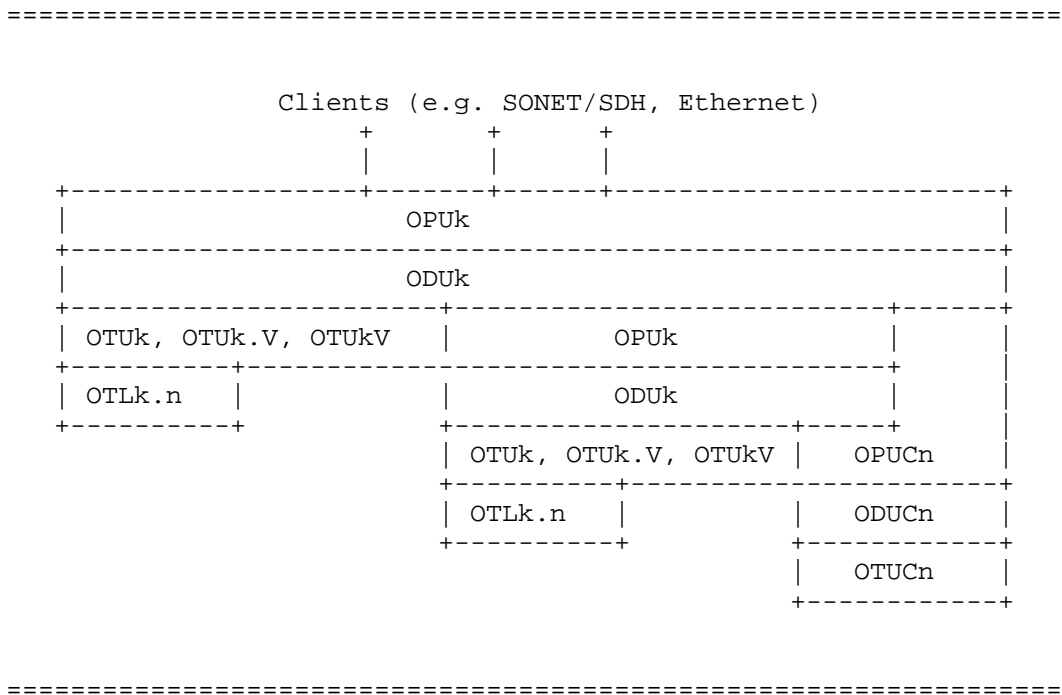


Figure 3: Digital Structure of OTN interfaces (from G.709:Figure 6-1)

#### 4. Applications and GMPLS Implications

##### 4.1. Applications and Challenges

Two typical scenarios are depicted in Appendix XIII of [ITU-T\_G709\_2016], which are also introduced into this document to help analyze the potential extension to GMPLS needed. Though these two scenarios are mainly introduced in G.709 to describe OTUCn sub rates application, they can also be used to describe general OTUCn application. One thing that should be note is these two scenarios are a little different from those described in [ITU-T\_G709\_2016], as the figure in this section include the OTSi(G) in to facilitate the description of the challenge brought by [ITU-T\_G709\_2016].

The first scenarios is depicted in Figure 4. This scenario deploys OTUCn/OTUCn-M between two line ports connecting two L1/L0 ODU cross connects (XC) within one optical transport network. One OTUCn is actually carried by one OTSi(G) or OTSiA.

As defined in [ITU-T\_G872], OTSiG is used to represent one or more OTSi as a group to carry a single client signal (e.g., OTUCn). The

OTSiG may have non-associated overhead, the combination of the OTSiG and OTSiG-O is represented by the OTSiA management/control abstraction.

In this scenario, it is clear that the OTUCn and ODUCn link can be automatically established, after/together with the setup of OTSi(G) or OTSiA, as both OTUCn and ODUCn perform section layer only. One client OTUCn signal is carried by one single huge OTSi signal or a group of OTSi. There is a 1:1 mapping relationship between OTUCn and OTSi(G) or OTSiA.

For example, one 400G OTUCn signal can be carried by one single 400G OTSi signal or one 400G OTUCn signal can be split into 4 different OTUC instances, with each instances carried by one OTSi. Those four OTSi function as a group to carry a single 400G OTUCn signal.

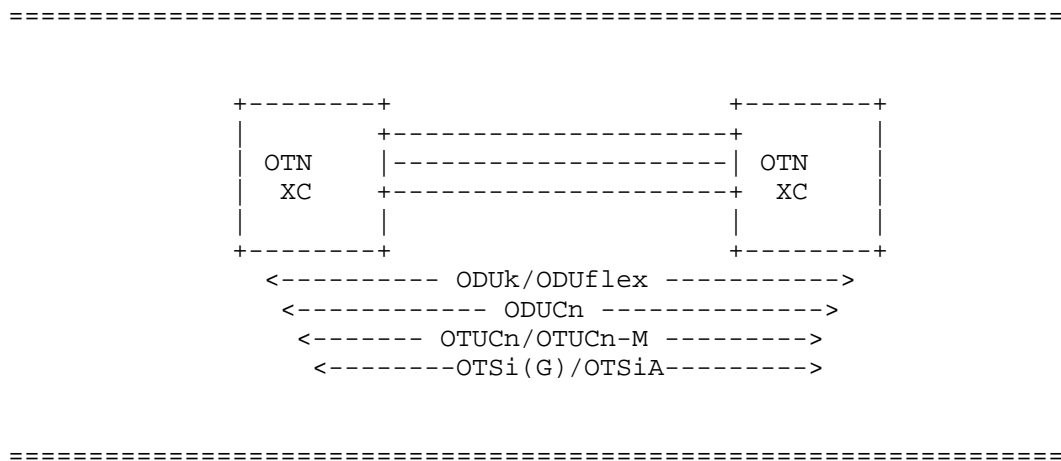


Figure 4: Scenario A

The second scenarios is depicted in Figure 4. This scenario deploys OTUCn/OTUCn-M between transponders which are in a different domain B, which are separated from the L1 ODU XCs in domain A and/or C. one end-to-end ODUCn is actually supported by three different OTUCn or OTUCn-M segments, which are in turn carried by OTSi(G) or OTSiA.

In the second scenario, OTUCn links will be established automatically after/together with the setup of OTSi(G) or OTSiA, while there are still some doubts about how the ODUCn link is established. In principle, it could/should be possible but it is not yet clear in details how the ODUCn link can be automatically setup.

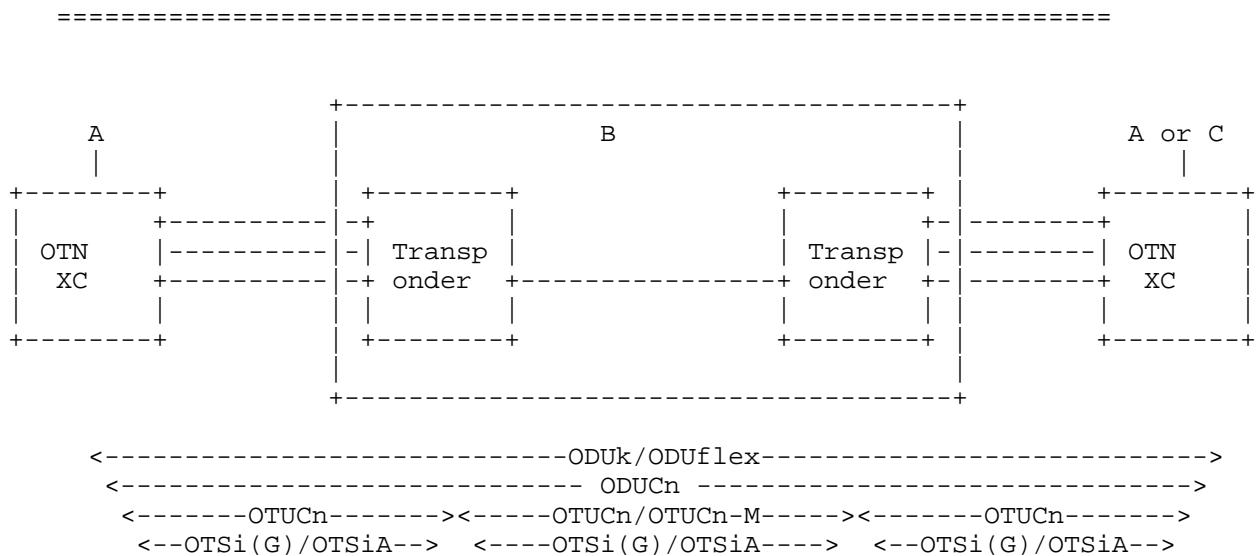


Figure 5: Scenario B

According to the above description, it can be concluded that some uncertainty about setup of ODUCn link still exist, and this uncertainty may have relationship with the progress in ITU-T. Based on the analysis, it is suggested that the scope of this draft should mainly focus on how to set up ODUk/ODUflex LSPs over ODUCn links, as also indicated in the figure above.

## 4.2. GMPLS Implications and Applicability

### 4.2.1. Implications and Applicability for GMPLS Signalling

Once the ODUCn link is configured, the GMPLS mechanisms defined in RFC7139 can be reused to set up ODUk/ODUflex LSP with no/few changes. As the resource on the ODUCn link which can be seen by the client ODUk/ODUflex is a serial of 5G slots, the label defined in RFC7139 is able to accommodate the requirement of the setup of ODUk/ODUflex over ODUCn link.

One thing should be note is the TPN used in RFC7139 and defined in G.709-2016 for ODUCn link. Since the TPN currently defined in G.709 for ODUCn link has 14 bits, while this field in RFC7139 only has 12 bits, some extension work is needed, but this is not so urgent since

for today networks scenarios 12 bits are enough, as it can support a single ODUCn link up to n=400, namely 40Tbit.

An example is given below to illustrate the label format defined in RFC7139 for multiplexing ODU4 onto ODUC10. One ODUC10 has 200 5G slots, and twenty of them are allocated to the ODU4. Along with the increase of "n", the label may become lengthy, an optimized label format may be needed.

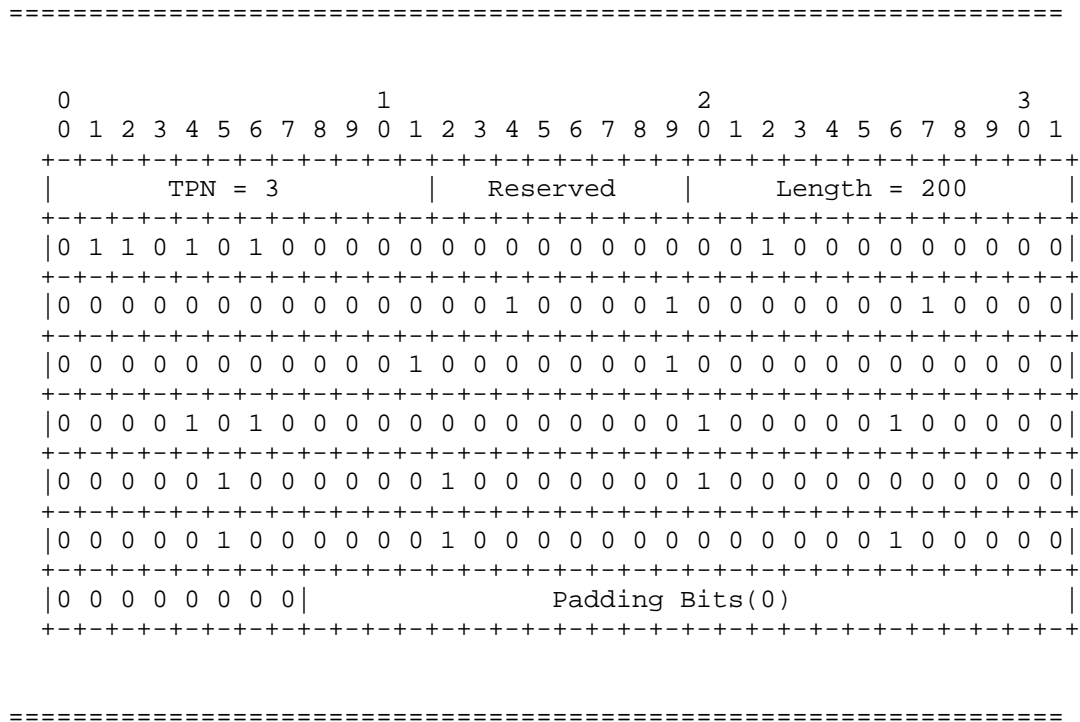


Figure 6: Label format

#### 4.2.2. Implications and Applicability for GMPLS Routing

For routing, we think that no extension to current mechanisms defined in RFC7138 are needed. Because, once one ODUCn link is up, we need to advertise only the resources that can be used on this ODUCn link and the multiplexing hierarchy on this link. Considering ODUCn link is already configured, it's the ultimate hierarchy of this multiplexing, there is no need to explicitly extent the ODUCn signal type in the routing.



The OSPF-TE extension defined in section 4 of RFC7138 can be used to advertise the resource information on the ODUCn link to direct the setup of ODUk/ODUflex.

5. Acknowledgements

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## 8. IANA Considerations

This memo includes no request to IANA.

## 9. Security Considerations

None.

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OTN Tunnel YANG Model  
draft-sharma-ccamp-otn-tunnel-model-01

Abstract

This document describes the YANG data model for OTN Tunnels.

Requirements Language

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

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## 1. Introduction

OTN transport networks can carry various types of client services. In many cases, the client signal is carried over an OTN tunnel across connected domains in a multi-domain network. These OTN services can either be transported or switched in the OTN network. If an OTN tunnel is switched, then additional parameters need to be provided to create a Mux OTN service.

This document provides YANG model for creating OTN tunnel. The model augments the TE Tunnel model, which is an abstract model to create TE Tunnels.

## 2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this draft is defined in . They are provided below for reference.

- o Brackets "[" and "]" enclose list keys.
- o Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).

- o Symbols after data node names: "?" means an optional node, "!" means a presence container, and "\*" denotes a list and leaf-list.
- o Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- o Ellipsis ("...") stands for contents of subtrees that are not shown.

### 3. Model Overview

#### 3.1. Mux Service in Multi-Domain OTN Network

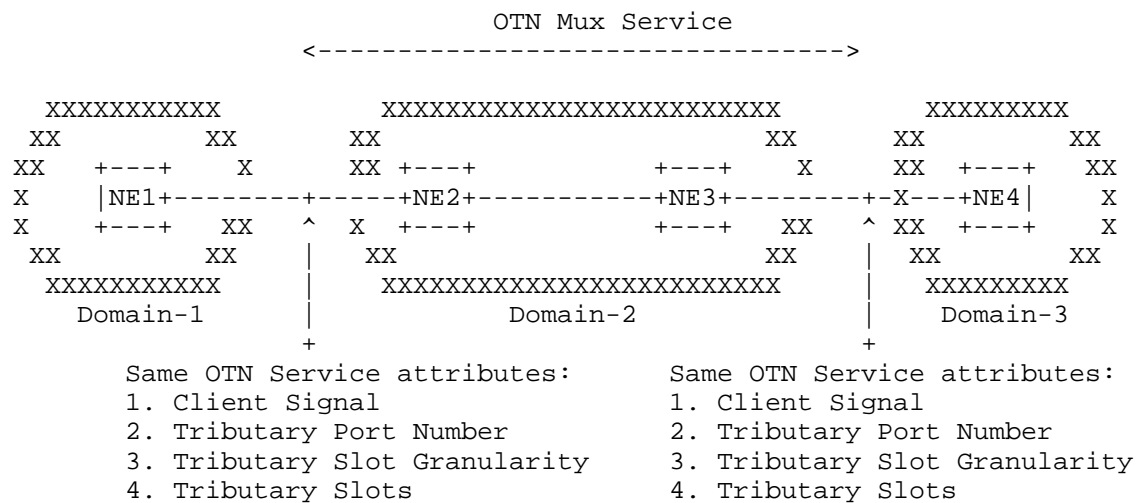


Figure 1: OTN Mux Service in a multi-domain network topology

Figure 1 shows a multi-domain OTN network with three domains. In this example, user wants to setup an end-to-end OTN service that passes through Domain-2. In order to create an OTN mux service in Domain-2, user will need to specify the exact details of the client side LO-ODU on NE2 and NE3, so that these service endpoints can be paired with the LO-ODU endpoints on NE1 and NE4, respectively.

Let's assume that ODU4 is the client side HO-ODU on NE2 and NE3, and the client signal is ODU2. User will need to specify the OTN client signal (ODU2 in this example), the Tributary Port Number (TPN), Tributary Slot Granularities (TSG) and tributary slots to be used.



As shown in the figure above, these service parameters must be the same between NE1 and NE2, and NE3 and NE4.

Once the OTN Mux service is setup in Domain-2, the incoming signal from either NE1 and/or NE4 will be switched inside Domain-2, and delivered to NE at the other end.

### 3.2. Bookended and Non-BookEnded OTN Tunnel

OTN tunnel model provides support for both bookended and non-bookended OTN tunnels.

For bookended tunnels, the same client signal is present on source and destination endpoints. For example, ODU2e bookended tunnel will have the same ODU2e client signal at both source and destination endpoints.

For non-bookended tunnels, different client signals are present on source and destination endpoints. For example, the client signal can be ODU2e on the source endpoint and the handoff at the destination can be 10GbE-LAN client signal.

### 3.3. Network and Client side tunnel services

The OTN tunnel model provides support for both network to network and client to client tunnels. For network to network tunnel, network termination points on source and destination node represent source and destination endpoints. For client to client tunnel, client termination points on source and destination node represent source and destination endpoints.

If a client to client tunnel needs to use one or more HO (or server) network to network tunnels, ERO and routing constraints, defined in the base TE model, can be used to route the client tunnel over one or more server tunnels.

### 3.4. OTN Tunnel YANG Tree

```

module: ietf-otn-tunnel
augment /te:te/te:tunnels/te:tunnel/te:config:
  +--rw payload-treatment?      enumeration
  +--rw src-client-signal?      identityref
  +--rw src-tpn?                uint16
  +--rw src-tsg?                identityref
  +--rw src-tributary-slot-count? uint16
  +--rw src-tributary-slots
  |   +--rw values*            uint8
  +--rw dst-client-signal?      identityref
  +--rw dst-tpn?                uint16
  +--rw dst-tsg?                identityref
  +--rw dst-tributary-slot-count? uint16
  +--rw dst-tributary-slots
  |   +--rw values*            uint8
augment /te:te/te:tunnels/te:tunnel/te:state:
  +--ro payload-treatment?      enumeration
  +--ro src-client-signal?      identityref
  +--ro src-tpn?                uint16
  +--ro src-tsg?                identityref
  +--ro src-tributary-slot-count? uint16
  +--ro src-tributary-slots
  |   +--ro values*            uint8
  +--ro dst-client-signal?      identityref
  +--ro dst-tpn?                uint16
  +--ro dst-tsg?                identityref
  +--ro dst-tributary-slot-count? uint16
  +--ro dst-tributary-slots
  |   +--ro values*            uint8

```

### 3.5. OTN Tunnel YANG Code

```

<CODE BEGINS>file "ietf-otn-tunnel@2017-03-11.yang"

module ietf-otn-tunnel {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-otn-tunnel";
  prefix "otn-tunnel";

  import ietf-te { prefix "te"; }
  import ietf-transport-types { prefix "tran-types"; }
  //import yang-ext { prefix ext; revision-date 2013-07-09; }

  organization

```

```
"IETF CCAMP Working Group";

contact
  "WG Web: <http://tools.ietf.org/wg/ccamp/>
  WG List: <mailto:ccamp@ietf.org>

  Editor: Anurag Sharma
          <mailto:AnSharma@infinera.com>

  Editor: Rajan Rao
          <mailto:rrao@infinera.com>

  Editor: Xian Zhang
          <mailto:zhang.xian@huawei.com>

  Editor: Kun Xiang
          <mailto:xiangkun@huawei.com>";

description
  "This module defines a model for OTN Tunnel Services.";

revision "2017-03-11" {
  description
    "Revision 0.3";
  reference "TBD";
}

grouping otn-tunnel-endpoint {
  description "Parameters for OTN tunnel.";

    leaf payload-treatment {
      type enumeration {
        enum switching;
        enum transport;
      }
      default switching;
      description
        "Treatment of the incoming payload. Payload can
        either be switched, or transported as is.";
    }

    leaf src-client-signal {
      type identityref {
        base tran-types:client-signal;
      }
      description
        "Client signal at the source endpoint of
        the tunnel.";
    }
  }
}
```

```
    }

    leaf src-tpn {
      type uint16 {
        range "0..4095";
      }
      description
        "Tributary Port Number. Applicable in case of mux
        services.";
      reference
        "RFC7139: GMPLS Signaling Extensions for Control of
        Evolving G.709 Optical Transport Networks.";
    }

    leaf src-tsg {
      type identityref {
        base tran-types:tributary-slot-granularity;
      }
      description
        "Tributary slot granularity. Applicable in case of mux
        services.";
      reference
        "G.709/Y.1331, February 2016: Interfaces for the
        Optical Transport Network (OTN)";
    }

    leaf src-tributary-slot-count {
      type uint16;
      description
        "Number of tributary slots used at the source.";
    }

    container src-tributary-slots {
      description
        "A list of tributary slots used by the client
        service. Applicable in case of mux services.";
      leaf-list values {
        type uint8;
        description
          "Tributary tributary slot value.";
        reference
          "G.709/Y.1331, February 2016: Interfaces for the
          Optical Transport Network (OTN)";
      }
    }

    leaf dst-client-signal {
      type identityref {
```

```
        base tran-types:client-signal;
    }
    description
        "Client signal at the destination endpoint of
        the tunnel.";
}

leaf dst-tpn {
    type uint16 {
        range "0..4095";
    }
    description
        "Tributary Port Number. Applicable in case of mux
        services.";
    reference
        "RFC7139: GMPLS Signaling Extensions for Control of
        Evolving G.709 Optical Transport Networks.";
}

leaf dst-tsg {
    type identityref {
        base tran-types:tributary-slot-granularity;
    }
    description
        "Tributary slot granularity. Applicable in case of mux
        services.";
    reference
        "G.709/Y.1331, February 2016: Interfaces for the
        Optical Transport Network (OTN)";
}

leaf dst-tributary-slot-count {
    type uint16;
    description
        "Number of tributary slots used at the destination.";
}

container dst-tributary-slots {
    description
        "A list of tributary slots used by the client
        service. Applicable in case of mux services.";
    leaf-list values {
        type uint8;
        description
            "Tributary slot value.";
        reference
            "G.709/Y.1331, February 2016: Interfaces for the
            Optical Transport Network (OTN)";
    }
}
```

```
    }
  }
}

/*
Note: Comment has been given to authors of TE Tunnel model to add
tunnel-types to the model in order to identify the technology
type of the service.

grouping otn-service-type {
  description
    "Identifies the OTN Service type.";
  container otn-service {
    presence "Indicates OTN Service.";
    description
      "Its presence identifies the OTN Service type.";
  }
} // otn-service-type

augment "/te:te/te:tunnels/te:tunnel/te:tunnel-types" {
  description
    "Introduce OTN service type for tunnel.";
  ext:augment-identifier otn-service-type-augment;
  uses otn-service-type;
}
*/

/*
Note: Comment has been given to authors of TE Tunnel model to add
list of endpoints under config to support P2MP tunnel.
*/
augment "/te:te/te:tunnels/te:tunnel/te:config" {
  description
    "Augment with additional parameters required for OTN
    service.";
  //ext:augment-identifier otn-tunnel-endpoint-config-augment;
  uses otn-tunnel-endpoint;
}

augment "/te:te/te:tunnels/te:tunnel/te:state" {
  description
    "Augment with additional parameters required for OTN
    service.";
  //ext:augment-identifier otn-tunnel-endpoint-state-augment;
  uses otn-tunnel-endpoint;
}

/*
```

Note: Comment has been given to authors of TE Tunnel model to add tunnel-lifecycle-event to the model. This notification is reported for all lifecycle changes (create, delete, and update) to the tunnel or lsp.

```
augment "/te:tunnel-lifecycle-event" {
  description
    "OTN service event";
  uses otn-service-type;
  uses otn-tunnel-params;

  list endpoint {
    key
      "endpoint-address tp-id";
    description
      "List of Tunnel Endpoints.";
    uses te:tunnel-endpoint;
    uses otn-tunnel-params;
  }
}
*/
}
```

<CODE ENDS>

### 3.6. Transport Types YANG Code

```
<CODE BEGINS> file "ietf-transport-types@2016-10-25.yang"

module ietf-transport-types {
  namespace "urn:ietf:params:xml:ns:yang:ietf-transport-types";
  prefix "tran-types";

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

    Editor: Anurag Sharma
           <mailto:AnSharma@infinera.com>

    Editor: Rajan Rao
           <mailto:rrao@infinera.com>

    Editor: Xian Zhang
```

```
<mailto:zhang.xian@huawei.com>";

description
  "This module defines transport types.";

revision "2016-10-25" {
  description
    "Revision 0.2";
  reference "TBD";
}

identity tributary-slot-granularity {
  description
    "Tributary slot granularity.";
  reference
    "G.709/Y.1331, February 2016: Interfaces for the
      Optical Transport Network (OTN)";
}

identity tsg-1.25G {
  base tributary-slot-granularity;
  description
    "1.25G tributary slot granularity.";
}

identity tsg-2.5G {
  base tributary-slot-granularity;
  description
    "2.5G tributary slot granularity.";
}

identity tributary-protocol-type {
  description
    "Base identity for protocol framing used by
      tributary signals.";
}

identity prot-OTU1 {
  base tributary-protocol-type;
  description
    "OTU1 protocol (2.66G)";
}

/*
identity prot-OTU1e {
  base tributary-protocol-type;
  description
    "OTU1e type (11.04G)";
}
```



```
    }

    identity prot-OTU1f {
        base tributary-protocol-type;
        description
            "OTU1f type (11.27G)";
    }

    /*
    identity prot-OTU2 {
        base tributary-protocol-type;
        description
            "OTU2 type (10.70G)";
    }

    identity prot-OTU2e {
        base tributary-protocol-type;
        description
            "OTU2e type (11.09G)";
    }

    /*
    identity prot-OTU2f {
        base tributary-protocol-type;
        description
            "OTU2f type (11.31G)";
    }
    */

    identity prot-OTU3 {
        base tributary-protocol-type;
        description
            "OTU3 type (43.01G)";
    }

    /*
    identity prot-OTU3e1 {
        base tributary-protocol-type;
        description
            "OTU3e1 type (44.57G)";
    }

    identity prot-OTU3e2 {
        base tributary-protocol-type;
        description
            "OTU3e2 type (44.58G)";
    }
    */
```

```
identity prot-OTU4 {
    base tributary-protocol-type;
    description
        "OTU4 type (111.80G)";
}

identity prot-OTUCn {
    base tributary-protocol-type;
    description
        "OTUCn type (beyond 100G)";
}

identity prot-ODU0 {
    base tributary-protocol-type;
    description
        "ODU0 protocol (1.24G).";
}

identity prot-ODU1 {
    base tributary-protocol-type;
    description
        "ODU1 protocol (2.49G).";
}

/*
identity prot-ODU1e {
    base tributary-protocol-type;
    description
        "ODU1e protocol (10.35G).";
}

identity prot-ODU1f {
    base tributary-protocol-type;
    description
        "ODU1f protocol (10.56G).";
}
*/

identity prot-ODU2 {
    base tributary-protocol-type;
    description
        "ODU2 protocol (10.03G).";
}

identity prot-ODU2e {
    base tributary-protocol-type;
    description
        "ODU2e protocol (10.39G).";
}
```

```
    }

    /*
    identity prot-ODU2f {
        base tributary-protocol-type;
        description
            "ODU2f protocol (10.60G).";
    }
    */

    identity prot-ODU3 {
        base tributary-protocol-type;
        description
            "ODU3 protocol (40.31G).";
    }

    /*
    identity prot-ODU3e1 {
        base tributary-protocol-type;
        description
            "ODU3e1 protocol (41.77G).";
    }

    identity prot-ODU3e2 {
        base tributary-protocol-type;
        description
            "ODU3e2 protocol (41.78G).";
    }
    */

    identity prot-ODU4 {
        base tributary-protocol-type;
        description
            "ODU4 protocol (104.79G).";
    }

    identity prot-ODUFlex-cbr {
        base tributary-protocol-type;
        description
            "ODU Flex CBR protocol for transporting constant bit
            rate signal.";
    }

    identity prot-ODUFlex-gfp {
        base tributary-protocol-type;
        description
            "ODU Flex GFP protocol for transporting stream of packets
            using Generic Framing Procedure.";
```

```
    }

    identity prot-ODUCn {
        base tributary-protocol-type;
        description
            "ODUCn protocol (beyond 100G).";
    }

    identity prot-1GbE {
        base tributary-protocol-type;
        description
            "1G Ethernet protocol";
    }

    identity prot-10GbE-LAN {
        base tributary-protocol-type;
        description
            "10G Ethernet LAN protocol";
    }

    identity prot-40GbE {
        base tributary-protocol-type;
        description
            "40G Ethernet protocol";
    }

    identity prot-100GbE {
        base tributary-protocol-type;
        description
            "100G Ethernet protocol";
    }

    identity client-signal {
        description
            "Base identity from which specific client signals for the
            tunnel are derived.";
    }

    identity client-signal-1GbE {
        base client-signal;
        description
            "Client signal type of 1GbE";
    }

    identity client-signal-10GbE-LAN {
        base client-signal;
        description
            "Client signal type of 10GbE LAN";
    }
```

```
    }

    identity client-signal-10GbE-WAN {
        base client-signal;
        description
            "Client signal type of 10GbE WAN";
    }

    identity client-signal-40GbE {
        base client-signal;
        description
            "Client signal type of 40GbE";
    }

    identity client-signal-100GbE {
        base client-signal;
        description
            "Client signal type of 100GbE";
    }

    identity client-signal-OC3_STM1 {
        base client-signal;
        description
            "Client signal type of OC3 & STM1";
    }

    identity client-signal-OC12_STM4 {
        base client-signal;
        description
            "Client signal type of OC12 & STM4";
    }

    identity client-signal-OC48_STM16 {
        base client-signal;
        description
            "Client signal type of OC48 & STM16";
    }

    identity client-signal-OC192_STM64 {
        base client-signal;
        description
            "Client signal type of OC192 & STM64";
    }

    identity client-signal-OC768_STM256 {
        base client-signal;
        description
            "Client signal type of OC768 & STM256";
    }
```

```
    }

    identity client-signal-ODU0 {
        base client-signal;
        description
            "Client signal type of ODU0 (1.24G)";
    }

    identity client-signal-ODU1 {
        base client-signal;
        description
            "ODU1 protocol (2.49G)";
    }

    identity client-signal-ODU2 {
        base client-signal;
        description
            "Client signal type of ODU2 (10.03G)";
    }

    identity client-signal-ODU2e {
        base client-signal;
        description
            "Client signal type of ODU2e (10.39G)";
    }

    identity client-signal-ODU3 {
        base client-signal;
        description
            "Client signal type of ODU3 (40.31G)";
    }

    /*
    identity client-signal-ODU3e2 {
        base client-signal;
        description
            "Client signal type of ODU3e2 (41.78G)";
    }
    */

    identity client-signal-ODU4 {
        base client-signal;
        description
            "Client signal type of ODU4 (104.79G)";
    }

    identity client-signal-ODUFlex-cbr {
        base client-signal;
```

```
        description
            "Client signal type of ODU Flex CBR";
    }

    identity client-signal-ODUFlex-gfp {
        base client-signal;
        description
            "Client signal type of ODU Flex GFP";
    }

    identity client-signal-ODUCn {
        base client-signal;
        description
            "Client signal type of ODU Cn (beyond 100G).";
    }

    identity client-signal-FC400 {
        base client-signal;
        description
            "Client signal type of Fibre Channel FC400.";
    }

    identity client-signal-FC800 {
        base client-signal;
        description
            "Client signal type of Fibre Channel FC800.";
    }

    identity client-signal-FICON-4G {
        base client-signal;
        description
            "Client signal type of Fibre Connection 4G.";
    }

    identity client-signal-FICON-8G {
        base client-signal;
        description
            "Client signal type of Fibre Connection 8G.";
    }
}
<CODE ENDS>
```

## 4. Security Considerations

TBD.

## 5. IANA Considerations

TBD.

## 6. Acknowledgements

TBD.

## 7. Normative References

- [G.709] "Interfaces for the Optical Transport Network(OTN)", G.709/Y.1331 Recommendation , June 2016.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", RFC 6020, DOI 10.17487/RFC6020, October 2010, <<http://www.rfc-editor.org/info/rfc6020>>.
- [RFC7139] Zhang, F., Ed., Zhang, G., Belotti, S., Ceccarelli, D., and K. Pithewan, "GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks", RFC 7139, DOI 10.17487/RFC7139, March 2014, <<http://www.rfc-editor.org/info/rfc7139>>.

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OTN Tunnel YANG Model  
draft-sharma-ccamp-otn-tunnel-model-02

Abstract

This document describes the YANG data model for OTN Tunnels.

Requirements Language

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

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## 1. Introduction

OTN transport networks can carry various types of client services. In many cases, the client signal is carried over an OTN tunnel across connected domains in a multi-domain network. These OTN services can either be transported or switched in the OTN network. If an OTN tunnel is switched, then additional parameters need to be provided to create a Mux OTN service.

This document provides YANG model for creating OTN tunnel. The model augments the TE Tunnel model, which is an abstract model to create TE Tunnels.

## 2. Terminology and Notations

A simplified graphical representation of the data model is used in this document. The meaning of the symbols in the YANG data tree presented later in this draft is defined in [I-D.ietf-netmod-rfc6087bis]. They are provided below for reference.

- o Brackets "[" and "]" enclose list keys.
- o Abbreviations before data node names: "rw" means configuration (read-write) and "ro" state data (read-only).
- o Symbols after data node names: "?" means an optional node, "!" means a presence container, and "\*" denotes a list and leaf-list.
- o Parentheses enclose choice and case nodes, and case nodes are also marked with a colon (":").
- o Ellipsis ("...") stands for contents of subtrees that are not shown.

## 3. Model Overview

### 3.1. Mux Service in Multi-Domain OTN Network

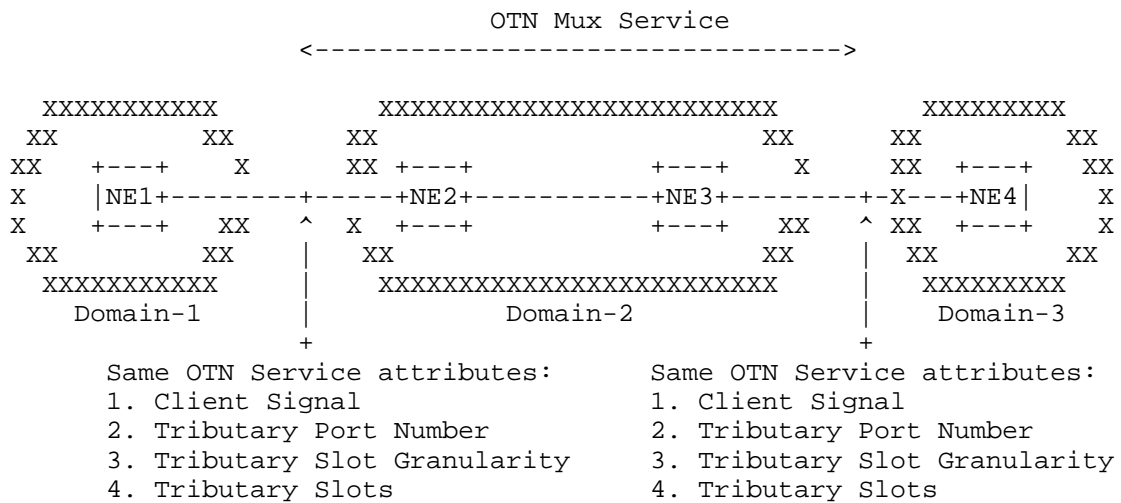


Figure 1: OTN Mux Service in a multi-domain network topology

Figure 1 shows a multi-domain OTN network with three domains. In this example, user wants to setup an end-to-end OTN service that passes through Domain-2. In order to create an OTN mux service in Domain-2, user will need to specify the exact details of the client side LO-ODU on NE2 and NE3, so that these service endpoints can be paired with the LO-ODU endpoints on NE1 and NE4, respectively.

Let's assume that ODU4 is the client side HO-ODU on NE2 and NE3, and the client signal is ODU2. User will need to specify the OTN client signal (ODU2 in this example), the Tributary Port Number (TPN), Tributary Slot Granularities (TSG) and tributary slots to be used. As shown in the figure above, these service parameters must be the same between NE1 and NE2, and NE3 and NE4.

Once the OTN Mux service is setup in Domain-2, the incoming signal from either NE1 and/or NE4 will be switched inside Domain-2, and delivered to NE at the other end.

### 3.2. Bookended and Non-BookEnded OTN Tunnel

OTN tunnel model provides support for both bookended and non-bookended OTN tunnels.

For bookended tunnels, the same client signal is present on source and destination endpoints. For example, ODU2e bookended tunnel will have the same ODU2e client signal at both source and destination endpoints.

For non-bookended tunnels, different client signals are present on source and destination endpoints. For example, the client signal can be ODU2e on the source endpoint and the handoff at the destination can be 10GbE-LAN client signal.

### 3.3. Network and Client side tunnel services

The OTN tunnel model provides support for both network to network and client to client tunnels. For network to network tunnel, network termination points on source and destination node represent source and destination endpoints. For client to client tunnel, client termination points on source and destination node represent source and destination endpoints.

If a client to client tunnel needs to use one or more HO (or server) network to network tunnels, ERO and routing constraints, defined in the base TE model, can be used to route the client tunnel over one or more server tunnels.

### 3.4. OTN Tunnel YANG Tree

```

module: ietf-otn-tunnel
augment /te:te/te:tunnels/te:tunnel/te:config:
  +--rw payload-treatment?      enumeration
  +--rw src-client-signal?      identityref
  +--rw src-tpn?                uint16
  +--rw src-tsg?                identityref
  +--rw src-tributary-slot-count? uint16
  +--rw src-tributary-slots
    | +--rw values*            uint8
  +--rw dst-client-signal?      identityref
  +--rw dst-tpn?                uint16
  +--rw dst-tsg?                identityref
  +--rw dst-tributary-slot-count? uint16
  +--rw dst-tributary-slots
    +--rw values*            uint8
augment /te:te/te:tunnels/te:tunnel/te:state:
  +--ro payload-treatment?      enumeration
  +--ro src-client-signal?      identityref
  +--ro src-tpn?                uint16
  +--ro src-tsg?                identityref
  +--ro src-tributary-slot-count? uint16
  +--ro src-tributary-slots
    | +--ro values*            uint8
  +--ro dst-client-signal?      identityref
  +--ro dst-tpn?                uint16
  +--ro dst-tsg?                identityref
  +--ro dst-tributary-slot-count? uint16
  +--ro dst-tributary-slots
    +--ro values*            uint8

```

### 3.5. OTN Tunnel YANG Code

```

<CODE BEGINS>file "ietf-otn-tunnel@2017-05-25.yang"

module ietf-otn-tunnel {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-otn-tunnel";
  prefix "otn-tunnel";

  import ietf-te { prefix "te"; }
  import ietf-transport-types { prefix "tran-types"; }
  //import yang-ext { prefix ext; revision-date 2013-07-09; }

```

```
organization
  "IETF CCAMP Working Group";

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description
  "This module defines a model for OTN Tunnel Services.";

revision "2017-05-25" {
  description
    "Revision 0.3";
  reference
    "draft-sharma-ccamp-otn-tunnel-model-02.txt";
}

grouping otn-tunnel-endpoint {
  description "Parameters for OTN tunnel.";

  leaf payload-treatment {
    type enumeration {
      enum switching;
      enum transport;
    }
    default switching;
    description
```

```
        "Treatment of the incoming payload. Payload can
        either be switched, or transported as is.";
    }

    leaf src-client-signal {
        type identityref {
            base tran-types:client-signal;
        }
        description
            "Client signal at the source endpoint of
            the tunnel.";
    }

    leaf src-tpn {
        type uint16 {
            range "0..4095";
        }
        description
            "Tributary Port Number. Applicable in case of mux
            services.";
        reference
            "RFC7139: GMPLS Signaling Extensions for Control of
            Evolving G.709 Optical Transport Networks.";
    }

    leaf src-tsg {
        type identityref {
            base tran-types:tributary-slot-granularity;
        }
        description
            "Tributary slot granularity. Applicable in case of
            mux services.";
        reference
            "G.709/Y.1331, February 2016: Interfaces for the
            Optical Transport Network (OTN)";
    }

    leaf src-tributary-slot-count {
        type uint16;
        description
            "Number of tributary slots used at the source.";
    }

    container src-tributary-slots {
        description
            "A list of tributary slots used by the client
            service. Applicable in case of mux services.";
        leaf-list values {
```



```
        type uint8;
        description
            "Tributary tributary slot value.";
        reference
            "G.709/Y.1331, February 2016: Interfaces for the
             Optical Transport Network (OTN)";
    }
}

leaf dst-client-signal {
    type identityref {
        base tran-types:client-signal;
    }
    description
        "Client signal at the destination endpoint of
         the tunnel.";
}

leaf dst-tpn {
    type uint16 {
        range "0..4095";
    }
    description
        "Tributary Port Number. Applicable in case of mux
         services.";
    reference
        "RFC7139: GMPLS Signaling Extensions for Control of
         Evolving G.709 Optical Transport Networks.";
}

leaf dst-tsg {
    type identityref {
        base tran-types:tributary-slot-granularity;
    }
    description
        "Tributary slot granularity. Applicable in case of
         mux services.";
    reference
        "G.709/Y.1331, February 2016: Interfaces for the
         Optical Transport Network (OTN)";
}

leaf dst-tributary-slot-count {
    type uint16;
    description
        "Number of tributary slots used at the destination.";
}
```

```
    container dst-tributary-slots {
      description
        "A list of tributary slots used by the client
        service. Applicable in case of mux services.";
      leaf-list values {
        type uint8;
        description
          "Tributary slot value.";
        reference
          "G.709/Y.1331, February 2016: Interfaces for the
          Optical Transport Network (OTN)";
      }
    }
  }

/*
Note: Comment has been given to authors of TE Tunnel model to add
tunnel-types to the model in order to identify the technology
type of the service.

grouping otn-service-type {
  description
    "Identifies the OTN Service type.";
  container otn-service {
    presence "Indicates OTN Service.";
    description
      "Its presence identifies the OTN Service type.";
  }
} // otn-service-type

augment "/te:te/te:tunnels/te:tunnel/te:tunnel-types" {
  description
    "Introduce OTN service type for tunnel.";
  ext:augment-identifier otn-service-type-augment;
  uses otn-service-type;
}
*/

/*
Note: Comment has been given to authors of TE Tunnel model to add
list of endpoints under config to support P2MP tunnel.
*/
augment "/te:te/te:tunnels/te:tunnel/te:config" {
  description
    "Augment with additional parameters required for OTN
    service.";
  //ext:augment-identifier otn-tunnel-endpoint-config-augment;
  uses otn-tunnel-endpoint;
```

```

    }

    augment "/te:te/te:tunnels/te:tunnel/te:state" {
        description
            "Augment with additional parameters required for OTN
            service.";
        //ext:augment-identifier otn-tunnel-endpoint-state-augment;
        uses otn-tunnel-endpoint;
    }

    /*
    Note: Comment has been given to authors of TE Tunnel model to
    add tunnel-lifecycle-event to the model. This notification is
    reported for all lifecycle changes (create, delete, and update)
    to the tunnel or lsp.
    augment "/te:tunnel-lifecycle-event" {
        description
            "OTN service event";
        uses otn-service-type;
        uses otn-tunnel-params;

        list endpoint {
            key
                "endpoint-address tp-id";
            description
                "List of Tunnel Endpoints.";
            uses te:tunnel-endpoint;
            uses otn-tunnel-params;
        }
    }
    */
}
<CODE ENDS>

```

### 3.6. Transport Types YANG Code

```

<CODE BEGINS> file "ietf-transport-types@2017-05-25.yang"

module ietf-transport-types {
    namespace "urn:ietf:params:xml:ns:yang:ietf-transport-types";
    prefix "tran-types";

    organization
        "IETF CCAMP Working Group";
    contact
        "WG Web: <http://tools.ietf.org/wg/ccamp/>"

```

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Editor: Yunbo Li  
<mailto:liyunbo@chinamobile.com>";

description  
"This module defines transport types.";

revision "2017-05-25" {  
 description  
 "Revision 0.3";  
 reference  
 "draft-sharma-ccamp-otn-tunnel-model-02.txt";  
}

identity tributary-slot-granularity {  
 description  
 "Tributary slot granularity.";  
 reference  
 "G.709/Y.1331, February 2016: Interfaces for the  
 Optical Transport Network (OTN)";  
}

identity tsg-1.25G {  
 base tributary-slot-granularity;  
 description  
 "1.25G tributary slot granularity.";  
}

identity tsg-2.5G {

```
        base tributary-slot-granularity;
        description
            "2.5G tributary slot granularity.";
    }

    identity tributary-protocol-type {
        description
            "Base identity for protocol framing used by
            tributary signals.";
    }

    identity prot-OTU1 {
        base tributary-protocol-type;
        description
            "OTU1 protocol (2.66G)";
    }

    /*
    identity prot-OTU1e {
        base tributary-protocol-type;
        description
            "OTU1e type (11.04G)";
    }

    identity prot-OTU1f {
        base tributary-protocol-type;
        description
            "OTU1f type (11.27G)";
    }
    */

    identity prot-OTU2 {
        base tributary-protocol-type;
        description
            "OTU2 type (10.70G)";
    }

    identity prot-OTU2e {
        base tributary-protocol-type;
        description
            "OTU2e type (11.09G)";
    }

    /*
    identity prot-OTU2f {
        base tributary-protocol-type;
        description
            "OTU2f type (11.31G)";
    }
    */
```

```
*/

identity prot-OTU3 {
    base tributary-protocol-type;
    description
        "OTU3 type (43.01G)";
}

/*
identity prot-OTU3e1 {
    base tributary-protocol-type;
    description
        "OTU3e1 type (44.57G)";
}

identity prot-OTU3e2 {
    base tributary-protocol-type;
    description
        "OTU3e2 type (44.58G)";
}
*/

identity prot-OTU4 {
    base tributary-protocol-type;
    description
        "OTU4 type (111.80G)";
}

identity prot-OTUCn {
    base tributary-protocol-type;
    description
        "OTUCn type (beyond 100G)";
}

identity prot-ODU0 {
    base tributary-protocol-type;
    description
        "ODU0 protocol (1.24G).";
}

identity prot-ODU1 {
    base tributary-protocol-type;
    description
        "ODU1 protocol (2.49G).";
}

/*
identity prot-ODU1e {
```

```
        base tributary-protocol-type;
        description
            "ODU1e protocol (10.35G).";
    }

    identity prot-ODU1f {
        base tributary-protocol-type;
        description
            "ODU1f protocol (10.56G).";
    }
    */

    identity prot-ODU2 {
        base tributary-protocol-type;
        description
            "ODU2 protocol (10.03G).";
    }

    identity prot-ODU2e {
        base tributary-protocol-type;
        description
            "ODU2e protocol (10.39G).";
    }

    /*
    identity prot-ODU2f {
        base tributary-protocol-type;
        description
            "ODU2f protocol (10.60G).";
    }
    */

    identity prot-ODU3 {
        base tributary-protocol-type;
        description
            "ODU3 protocol (40.31G).";
    }

    /*
    identity prot-ODU3e1 {
        base tributary-protocol-type;
        description
            "ODU3e1 protocol (41.77G).";
    }

    identity prot-ODU3e2 {
        base tributary-protocol-type;
        description
```

```
        "ODU3e2 protocol (41.78G).";
    }
    */

    identity prot-ODU4 {
        base tributary-protocol-type;
        description
            "ODU4 protocol (104.79G).";
    }

    identity prot-ODUFlex-cbr {
        base tributary-protocol-type;
        description
            "ODU Flex CBR protocol for transporting constant bit
            rate signal.";
    }

    identity prot-ODUFlex-gfp {
        base tributary-protocol-type;
        description
            "ODU Flex GFP protocol for transporting stream of packets
            using Generic Framing Procedure.";
    }

    identity prot-ODUCn {
        base tributary-protocol-type;
        description
            "ODUCn protocol (beyond 100G).";
    }

    identity prot-1GbE {
        base tributary-protocol-type;
        description
            "1G Ethernet protocol";
    }

    identity prot-10GbE-LAN {
        base tributary-protocol-type;
        description
            "10G Ethernet LAN protocol";
    }

    identity prot-40GbE {
        base tributary-protocol-type;
        description
            "40G Ethernet protocol";
    }
}
```



```
identity prot-100GbE {
    base tributary-protocol-type;
    description
        "100G Ethernet protocol";
}

identity client-signal {
    description
        "Base identity from which specific client signals for the
        tunnel are derived.";
}

identity client-signal-1GbE {
    base client-signal;
    description
        "Client signal type of 1GbE";
}

identity client-signal-10GbE-LAN {
    base client-signal;
    description
        "Client signal type of 10GbE LAN";
}

identity client-signal-10GbE-WAN {
    base client-signal;
    description
        "Client signal type of 10GbE WAN";
}

identity client-signal-40GbE {
    base client-signal;
    description
        "Client signal type of 40GbE";
}

identity client-signal-100GbE {
    base client-signal;
    description
        "Client signal type of 100GbE";
}

identity client-signal-OC3_STM1 {
    base client-signal;
    description
        "Client signal type of OC3 & STM1";
}
```

```
identity client-signal-OC12_STM4 {
    base client-signal;
    description
        "Client signal type of OC12 & STM4";
}

identity client-signal-OC48_STM16 {
    base client-signal;
    description
        "Client signal type of OC48 & STM16";
}

identity client-signal-OC192_STM64 {
    base client-signal;
    description
        "Client signal type of OC192 & STM64";
}

identity client-signal-OC768_STM256 {
    base client-signal;
    description
        "Client signal type of OC768 & STM256";
}

identity client-signal-ODU0 {
    base client-signal;
    description
        "Client signal type of ODU0 (1.24G)";
}

identity client-signal-ODU1 {
    base client-signal;
    description
        "ODU1 protocol (2.49G)";
}

identity client-signal-ODU2 {
    base client-signal;
    description
        "Client signal type of ODU2 (10.03G)";
}

identity client-signal-ODU2e {
    base client-signal;
    description
        "Client signal type of ODU2e (10.39G)";
}
```

```
identity client-signal-ODU3 {
    base client-signal;
    description
        "Client signal type of ODU3 (40.31G)";
}

/*
identity client-signal-ODU3e2 {
    base client-signal;
    description
        "Client signal type of ODU3e2 (41.78G)";
}
*/

identity client-signal-ODU4 {
    base client-signal;
    description
        "Client signal type of ODU4 (104.79G)";
}

identity client-signal-ODUFlex-cbr {
    base client-signal;
    description
        "Client signal type of ODU Flex CBR";
}

identity client-signal-ODUFlex-gfp {
    base client-signal;
    description
        "Client signal type of ODU Flex GFP";
}

identity client-signal-ODUCn {
    base client-signal;
    description
        "Client signal type of ODUCn (beyond 100G).";
}

identity client-signal-FC400 {
    base client-signal;
    description
        "Client signal type of Fibre Channel FC400.";
}

identity client-signal-FC800 {
    base client-signal;
    description
        "Client signal type of Fibre Channel FC800.";
```

```
    }  
  
    identity client-signal-FICON-4G {  
        base client-signal;  
        description  
            "Client signal type of Fibre Connection 4G.";  
    }  
  
    identity client-signal-FICON-8G {  
        base client-signal;  
        description  
            "Client signal type of Fibre Connection 8G.";  
    }  
}  
<CODE ENDS>
```

#### 4. Security Considerations

TBD.

#### 5. IANA Considerations

TBD.

#### 6. Acknowledgements

TBD.

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## 8. Normative References

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Bierman, A., "Guidelines for Authors and Reviewers of YANG Data Model Documents", draft-ietf-netmod-rfc6087bis-12 (work in progress), March 2017.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.

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## Abstract

This document analyses how YANG models being defined by IETF (TEAS and CCAMP WG in particular) can be used to support Use Case 1 (single-domain with single-layer) scenarios as referenced later in this document.

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## 1. Introduction

This document analyses how YANG models being developed by IETF (TEAS and CCAMP WG) can be used to support Use Case 1 (single-domain with single-layer) scenarios as described in [TNBI- UseCases].



### 1.1. Assumptions

This document is analyzing how existing models developed by the IETF can be used at the MPI between the Transport PNC and the MDSC to support the use case 1 scenarios as defined in section 3 of [TNBI-UseCases].

This document assumes the applicability of the YANG models to the ACTN interfaces as defined in [ACTN-YANG] and therefore considers the TE Topology YANG model defined in [TE-TOPO], with the OTN Topology augmentation defined in [OTN-TOPO] and the TE Tunnel YANG model defined in [TE-TUNNEL], with the OTN Tunnel augmentation defined in [OTN-TUNNEL].

The analysis of how to use the attributes in the I2RS Topology YANG model, defined in [I2RS-TOPO], is for further study.

Moreover this document is making the following assumptions, still to be validated with TEAS WG:

1. The MDSC can request, at the MPI, the Transport PNC to setup a Transit Tunnel Segment using the TE Tunnel YANG model: in this case, since the endpoints of the E2E Tunnel are outside the domain controlled by the Transport PNC, the MDSC would not specify any source or destination TTP (i.e., it would leave the source, destination, src-tp-id and dst-tp-id attributes empty) and it would use the explicit-route-object list to specify the ingress and egress links of the Transit Tunnel Segment.
2. The Transport PNC provides to the MDSC, at the MPI, the list of available timeslots on the access links using the TE Topology YANG model and OTN Topology augmentation. The TE Topology YANG model in [TE-TOPO] is being updated to report the label set information.

### 1.2. Feedbacks provided to the IETF Working Groups

The analysis done in this version of this document has triggered the following feedbacks to TEAS WG:

- o On-going discussion about how to use the TE Tunnel YANG model in [TE-TUNNEL] to support tunnel segments.
- o Need to change TE Tunnel YANG model in [TE-TUNNEL] to clarify that the router-id and interface-id attributes in the unnumbered explicit-route-object corresponds to the te-node-id and te-tp-id attributes identifying an LTP in the TE Topology YANG model.

- o Need to add information about the label set (e.g., list of available timeslots) in the TE Topology and TE Tunnel YANG models.
- o Some detailed fixes to the TE Tunnel YANG model in [TE-TUNNEL] have also been identified during the validation of the JSON examples against the TE Tunnel YANG model.

## 2. Conventions used in this document

This document provides some detailed JSON code examples to describe how the YANG models being developed by IETF (TEAS and CCAMP WG in particular) can be used.

The examples are provided using JSON because JSON code is easier for humans to read and write.

Different objects need to have an identifier. The convention used to create mnemonic identifiers is to use the object name (e.g., S3 for node S3), followed by its type (e.g., NODE), separated by an "-", followed by "-ID". For example the mnemonic identifier for node S3 would be S3-NODE-ID.

JSON language does not support the insertion of comments that have been instead found to be useful when writing the examples. This document inserts comments into the JSON code as JSON name/value pair with the JSON name string starting with the "://" characters. For example, when describing the example of a TE Topology instance representing the ODU Abstract Topology exposed by the Transport PNC, the following comment has been added to the JSON code:

```
"// comment": "ODU Abstract Topology @ MPI",
```

The JSON code examples provided in this document have been validated against the YANG models following the validation process described in Appendix A, which would not consider the comments.

In order to have successful validation of the examples, some numbering scheme has been defined to assign identifiers to the different entities which would pass the syntax checks. In that case, to simplify the reading, another JSON name/value pair, formatted as a comment and using the mnemonic identifiers is also provided. For example, the identifier of node S3 (S3-NODE-ID) has been assumed to be "10.0.0.3" and would be shown in the JSON code example using the two JSON name/value pair:

```
"// te-node-id": "S3-NODE-ID",
```

```
"te-node-id": "10.0.0.3",
```

The first JSON name/value pair will be automatically removed in the first step of the validation process while the second JSON name/value pair will be validate against the YANG model definitions.

### 3. High-level Overview

Use Case 1 is described in [TNBI-UseCases] as a single-domain with single layer network scenario supporting different types of services. This section provides an high-level overview of how IETF YANG models can be used to support these uses cases at the MPI between the Transport PNC and the MDSC.

Section 3.1 describes the topology abstraction provided to the MDSC by the Transport PNC at the MPI.

Section 3.2 describes how the difference services, defined in section 3.3 of [TNBI-UseCases], can be requested to the Transport PNC by the MDSC at the MPI.

#### 3.1. Topology Abstraction

##### 3.1.1. ODU White Topology Abstraction

In case the Transport PNC exports to the MDSC a white topology, at the MPI there will be one TE Topology instance for the ODU layer (called "ODU Topology") containing one TE Node (called "ODU Node") for each physical node, as shown in Figure 1 below.

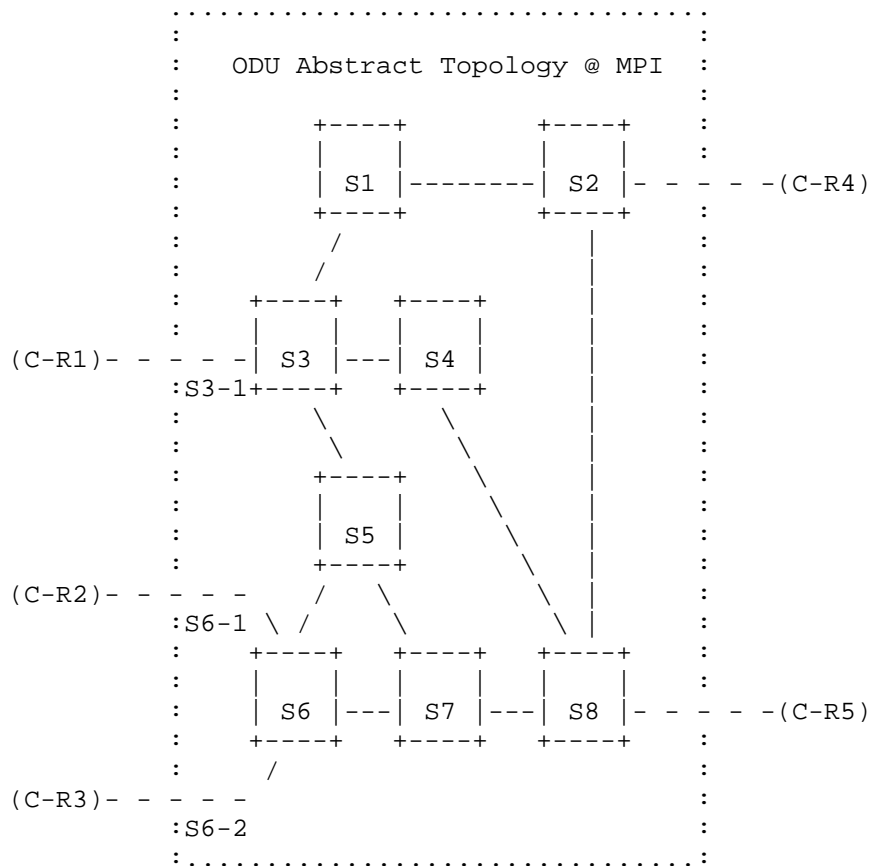


Figure 1 White Topology Abstraction (ODU Topology)

The ODU Nodes in Figure 1 are using with the same names as the physical nodes to simplify the description of the mapping between the ODU Nodes exposed by the Transport PNCs at the MPI and the physical nodes in the data plane.

As described in section 3.2 of [TNBI-UseCases], it is assumed that the physical links between the physical nodes are pre-configured up to the OTU4 trail using mechanisms which are outside the scope of this document. The Transport PNC exports to the MDSC via the MPI, one TE Link (called "ODU Link") for each of these physical links.

Access links in Figure 1 are shown as ODU Links: the modeling of the access links for other access technologies is currently an open issue.

The "external-domain" container allows the MDSC to glue together the ODU Topology provided by the Transport PNC with the information provided by the IP PNC to know which access link is connected with each link/router in the IP domain (e.g., that C-R1 is connected with the access link terminating on S3-1 LTP in the ODU Topology).

### 3.2. Service Configuration

#### 3.2.1. ODU Transit Service

In this case, the access links are configured as ODU Link, as described in section 3.1.1 above.

As described in section 3.3.1 of [TNBI-UseCases], the MDSC needs to setup an ODU2 trail, supporting an IP link, between C-R1 and C-R3.

From the topology information described in section 3.1.1 above, the MDSC can know that C-R1 is attached to the access link terminating on S3-1 LTP in the ODU Topology and that C-R3 is attached to the access link terminating on S6-2 LTP in the ODU Topology.

Based on the assumption 1) in section Error! Reference source not found., MDSC would then request Transport PNC to setup an ODU2 (Transit Segment) Tunnel between S3-1 and S6-2 LTPs:

- o Source and Destination TTP are not specified (since it is a Transit Tunnel)
- o Ingress and egress points are indicated in the explicit-route-objects of the primary path:
  - o The first element of the explicit-route-objects references the access link terminating on S3-1 LTP
  - o Last element of the explicit-route-objects references the access link terminating on S6-2 LTP

The configuration of the timeslots used by the ODU2 connection within the transport network domain (i.e., on the internal links) is a matter of the Transport PNC and its interactions with the physical network elements and therefore is outside the scope of this document.

However, the configuration of the timeslots used by the ODU2 connection at the edge of the transport network domain (i.e., on the access links) needs to take into account not only the timeslots available on the physical nodes at the edge of the transport network domain (e.g., S3 and S6) but also on the devices, outside of the

transport network domain, connected through these access links (e.g., C-R1 and C-R3).

Based on the assumption 2) in section Error! Reference source not found., MDSC, when requesting the Transport PNC to setup the (Transit Segment) ODU2 Tunnel, it would also configure the timeslots to be used on the access links. The MDSC can know the timeslots which are available on the edge OTN Node (e.g., S3 and S6) from the OTN Topology information exposed by the Transport PNC at the MPI as well as the timeslots which are available on the devices, outside of the transport network domain, connected through these access links (e.g., C-R1 and C-R3) by means which are outside the scope of this document.

The Transport PNC performs path computation and sets up the ODU2 cross-connections within the physical nodes S3, S5 and S6, as shown in section 4.3.1 of [TNBI-UseCases].

The Transport PNC reports the status of the created ODU2 (Transit Segment) Tunnel and its path within the ODU Topology as shown in Figure 2 below:

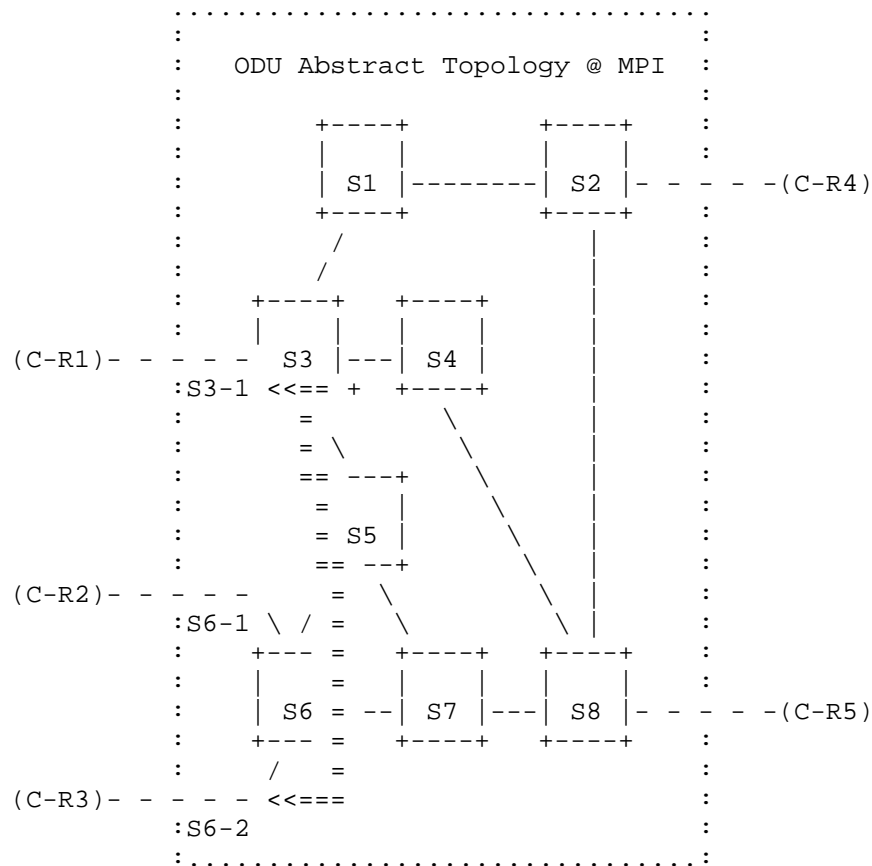


Figure 2 ODU2 Transit Tunnel

### 3.2.2. OTN Client Private Line Service

To be added

### 3.2.3. EPL over ODU Service

To be added

#### 4. Topology Abstraction: detailed JSON examples

##### 4.1. ODU White Topology Abstraction

Section 3.1.1 describes how the Transport PNC can provide a white topology abstraction to the MDSC via the MPI. Figure 1 is an example of such ODU Topology.

This section provides the detailed JSON code describing this ODU Topology, using the [TE-TOPO] and [OTN-TOPO] YANG models.

Note that this example is based on -09 version of [TE-TOPO] and on the -00 version of [OTN-TOPO]. Further changes to align with latest updates of these YANG models will be provided in the future version of this document.

JSON code "use-case-1-topology-01.json" has been provided at in the appendix of this document.

#### 5. Service Configuration: detailed JSON examples

##### 5.1. ODU Transit Service

Section 3.2.1 describes how the MDSC can request a Transport PNC, via the MPI, to setup an ODU2 transit service over an ODU Topology described in section 3.1.1.

This section provides the detailed JSON code describing this ODU Topology, using the [TE-TUNNEL] and [OTN-TUNNEL] YANG models.

Note that this example is based on -06 version of [TE-TUNNEL] and on the -02 version of [OTN-TUNNEL]. Further changes to align with latest updates of these YANG models will be provided in the future version of this document.

JSON code "use-case-1-odu2-service-01.json" has been provided at in the appendix of this document.

#### 6. Security Considerations

This section is for further study

#### 7. IANA Considerations

This document requires no IANA actions.



## 8. Conclusions

This section is for further study

## 9. References

### 9.1. Normative References

[TNBI-UseCases] Busi, I., King, D. et al, "Transport Northbound Interface Use Cases", draft-tnbidt-ccamp-transport-nbi-use-cases, work in progress.

[TE-TOPO] Liu, X. et al., "YANG Data Model for TE Topologies", draft-ietf-teas-yang-te-topo, work in progress.

[OTN-TOPO] Zheng, H. et al., "A YANG Data Model for Optical Transport Network Topology", draft-ietf-ccamp-otn-topo-yang, work in progress.

[TE-TUNNEL] Saad, T. et al., "A YANG Data Model for Traffic Engineering Tunnels and Interfaces", draft-ietf-teas-yang-te, work in progress.

[OTN-TUNNEL] Zheng, H. et al., "OTN Tunnel YANG Model", draft-sharma-ccamp-otn-tunnel-model, work in progress.

### 9.2. Informative References

[ACTN-YANG] Zhang, X. et al., "Applicability of YANG models for Abstraction and Control of Traffic Engineered Networks", draft-zhang-teas-actn-yang, work in progress.

[I2RS-TOPO] Clemm, A. et al., "A Data Model for Network Topologies", draft-ietf-i2rs-yang-network-topo, work in progress.

## 10. Acknowledgments

The authors would like to thank all members of the Transport NBI Design Team involved in the definition of use cases, gap analysis and guidelines for using the IETF YANG models at the Northbound Interface (NBI) of a Transport SDN Controller.

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Gonzalez de Dios, Hans Bjursrom and Italo Busi for having initiated the work on gap analysis for transport NBI and having provided foundations work for the development of this document.

The authors would like to thank the authors of the TE Topology and Tunnel YANG models [TE-TOPO] and [TE-TUNNEL], in particular Igor Bryskin, Vishnu Pavan Beeram, Tarek Saad and Xufeng Liu, for their support in addressing any gap identified during the analysis work.

This document was prepared using 2-Word-v2.0.template.dot.

## Appendix A. Validating a JSON fragment against a YANG Model

The objective is to have a tool that allows validating whether a piece of JSON code is compliant with a YANG model without using a client/server.

### A.1. DSDL-based approach

The idea is to generate a JSON driver file (JTOX) from YANG, then use it to translate JSON to XML and validate it against the DSDL schemas, as shown in Figure 3.

Useful link: <https://github.com/mbj4668/pyang/wiki/XmlJson>

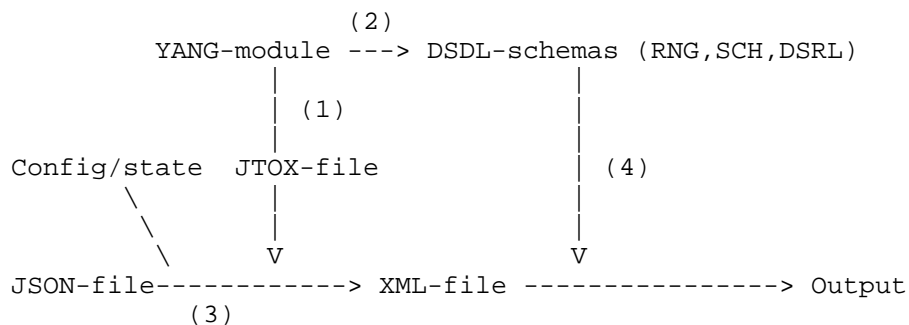


Figure 3 - DSDL-based approach for JSON code validation

In order to allow the use of comments following the convention defined in section 0 without impacting the validation process, these comments will be automatically removed from the JSON-file that will be validate.

### A.2. Why not using a XSD-based approach

This approach has been analyzed and discarded because no longer supported by pyang.

The idea is to convert YANG to XSD, JSON to XML and validate it against the XSD, as shown in Figure 4:

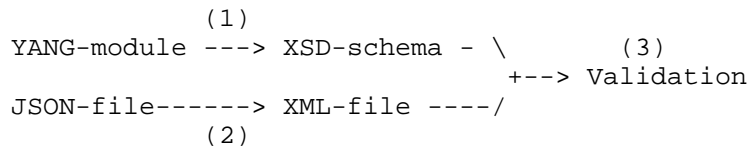


Figure 4 - XSD-based approach for JSON code validation

The pyang support for the XSD output format was deprecated in 1.5 and removed in 1.7.1. However pyang 1.7.1 is necessary to work with YANG 1.1 so the process shown in Figure 4 will stop just at step (1).

#### A.3. JSON Code: use-case-1-topology-01.json

The JSON code for this use case is currently located on GitHub at:

<https://github.com/danielkinguk/transport-nbi/blob/master/Internet-Drafts/Use-Case-1-Analysis/use-case-1-topology-01.json>

#### A.4. JSON Code: use-case-1-odu2-service-01.json

The JSON code for this use case is currently located on GitHub at:

<https://github.com/danielkinguk/transport-nbi/blob/master/Internet-Drafts/Use-Case-1-Analysis/use-case-1-odu2-service-01.json>

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draft-tnbidt-ccamp-transport-nbi-analysis-uc1-01

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## Abstract

This document analyses how YANG models being defined by IETF (TEAS and CCAMP WGs in particular) can be used to support Use Case 1 (single-domain with single-layer) scenarios, as referenced later in this document.

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## 1. Introduction

This document analyses how YANG models being developed by IETF (TEAS and CCAMP WGs) can be used to support Use Case 1 (single-domain with single-layer) scenarios, as described in [TNBI-UseCases].



### 1.1. Assumptions

This document analyses how existing models developed by the IETF can be used at the MPI between the Transport PNC and the MDSC to support the use case 1 scenarios, as defined in section 3 of [TNBI-UseCases].

This document assumes the applicability of the YANG models to the ACTN interfaces as defined in [ACTN-YANG] and therefore considers the TE Topology YANG model defined in [TE-TOPO], with the OTN Topology augmentation defined in [OTN-TOPO] and the TE Tunnel YANG model defined in [TE-TUNNEL], with the OTN Tunnel augmentation defined in [OTN-TUNNEL].

The analysis of how to use the attributes in the I2RS Topology YANG model, defined in [I2RS-TOPO], is for further study.

Moreover, this document is making the following assumptions, still to be validated with TEAS WG:

1. The MDSC can request, at the MPI, the Transport PNC to setup a Transit Tunnel Segment using the TE Tunnel YANG model: in this case, since the endpoints of the E2E Tunnel are outside the domain controlled by the Transport PNC, the MDSC would not specify any source or destination TTP (i.e., it would leave the source, destination, src-tp-id and dst-tp-id attributes empty) and it would use the explicit-route-object list to specify the ingress and egress links of the Transit Tunnel Segment.
2. The Transport PNC provides to the MDSC, at the MPI, the list of available timeslots on the access links using the TE Topology YANG model and OTN Topology augmentation. The TE Topology YANG model in [TE-TOPO] is being updated to report the label set information.

### 1.2. Feedbacks provided to the IETF Working Groups

The analysis done in this version of this document has triggered the following feedbacks to CCAMP WG:

- o A set of YANG models have been submitted in draft-zheng-ccamp-client-topo-yang and draft-zheng-ccamp-otn-client-signal-yang, providing an initial proposal, to be reviewed and discussed by the DT and the CCAMP WG, to resolve the open issues for EPL, other OTN client Private Line and EVPL services described in this version of the document.

## 2. Conventions used in this document

This document provides some detailed JSON code examples to describe how the YANG models being developed by IETF (TEAS and CCAMP WG in particular) can be used.

The examples are provided using JSON because JSON code is easier for humans to read and write.

Different objects need to have an identifier. The convention used to create mnemonic identifiers is to use the object name (e.g., S3 for node S3), followed by its type (e.g., NODE), separated by an "-", followed by "-ID". For example the mnemonic identifier for node S3 would be S3-NODE-ID.

JSON language does not support the insertion of comments that have been instead found to be useful when writing the examples. This document inserts comments into the JSON code as JSON name/value pair with the JSON name string starting with the "//" characters. For example, when describing the example of a TE Topology instance representing the ODU Abstract Topology exposed by the Transport PNC, the following comment has been added to the JSON code:

```
"// comment": "ODU Abstract Topology @ MPI",
```

The JSON code examples provided in this document have been validated against the YANG models following the validation process described in Appendix A, which would not consider the comments.

In order to have successful validation of the examples, some numbering scheme has been defined to assign identifiers to the different entities which would pass the syntax checks. In that case, to simplify the reading, another JSON name/value pair, formatted as a comment and using the mnemonic identifiers is also provided. For example, the identifier of node S3 (S3-NODE-ID) has been assumed to be "10.0.0.3" and would be shown in the JSON code example using the two JSON name/value pair:

```
"// te-node-id": "S3-NODE-ID",
```

```
"te-node-id": "10.0.0.3",
```

The first JSON name/value pair will be automatically removed in the first step of the validation process while the second JSON name/value pair will be validate against the YANG model definitions.

### 3. High-level Overview

Use Case 1 is described in [TNBI-UseCases] as a single-domain with single layer network scenario supporting different types of services. This section provides a high-level overview of how IETF YANG models can be used to support these uses cases at the MPI between the Transport PNC and the MDSC.

Section 3.1 describes the topology abstraction provided to the MDSC by the Transport PNC at the MPI.

Section 3.2 describes how the difference services, defined in section 4.3 of [TNBI-UseCases], can be requested to the Transport PNC by the MDSC at the MPI.

#### 3.1. Topology Abstraction

##### 3.1.1. ODU White Topology Abstraction

In case the Transport PNC exports to the MDSC a white topology, at the MPI there will be one TE Topology instance for the ODU layer (called "ODU Topology") containing one TE Node (called "ODU Node") for each physical node, as shown in Figure 1 below.

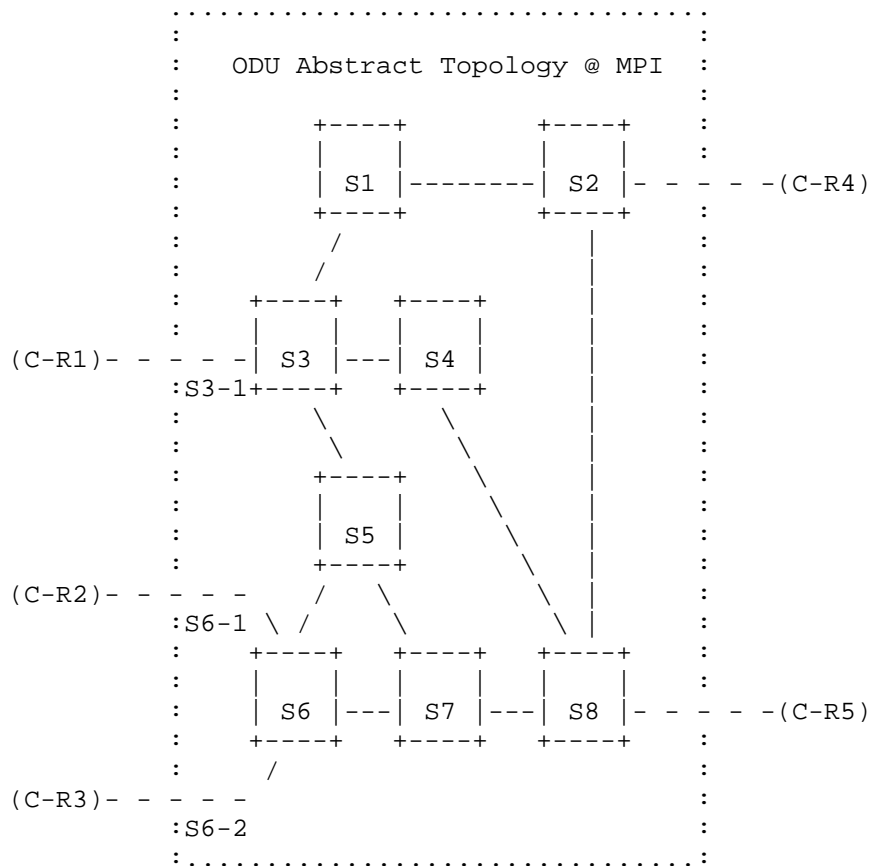


Figure 1 White Topology Abstraction (ODU Topology)

The ODU Nodes in Figure 1 are using with the same names as the physical nodes to simplify the description of the mapping between the ODU Nodes exposed by the Transport PNCs at the MPI and the physical nodes in the data plane. This does not correspond to the reality of the usage of the topology model, as described in section 4.3 of [TE-TOPO], in which renaming by the client it is necessary.

As described in section 3.2 of [TNBI-UseCases], it is assumed that the physical links between the physical nodes are pre-configured up to the OTU4 trail using mechanisms which are outside the scope of this document. The Transport PNC exports to the MDSC via the MPI, one TE Link (called "ODU Link") for each of these physical links.

Access links in Figure 1 are shown as ODU Links: the modeling of the access links for other access technologies is currently an open issue.

The modeling of the access link in case of non-ODU access technology, has also an impact on the need to model ODU TTPs and layer transition capabilities on the edge nodes (e.g., nodes S2, S3, S6 and S8 in Figure 1).

If, for example, the physical NE S6, is implemented in a "pizza box", the data plane would have only set of ODU termination resources (where up to 2xODU4, 4xODU3, 20xODU2, 80xODU1, 160xODU0 and 160xODUflex can be terminated). The traffic coming from each of the 10GE access links can be mapped into any of these ODU terminations.

Instead if, for example, the physical NE S6 can be implemented as a multi-board system where access links reside on different/dedicated access cards with separated set of ODU termination resources (where up to 1xODU4, 2xODU3, 10xODU2, 40xODU1, 80xODU0 and 80xODUflex for each resource can be terminated). The traffic coming from one 10GE access links can be mapped only into the ODU terminations which reside on the same access card.

The more generic implementation option for a physical NE (e.g., S6) would be case is of a multi-board system with multiple access cards with separated sets of access links and ODU termination resources (where up to 1xODU4, 2xODU3, 10xODU2, 40xODU1, 80xODU0 and 80xODUflex for each resource can be terminated). The traffic coming from each of the 10GE access links on one access card can be mapped only into any of the ODU terminations which reside on the same access card.

In the last two cases, only the ODUs terminated on the same access card where the access links resides can carry the traffic coming from that 10GE access link. Terminated ODUs can instead be sent to any of the OTU4 interfaces

In all these cases, terminated ODUs can be sent to any of the OTU4 interfaces assuming the implementation is based on a non-blocking ODU cross-connect.

If the access links are reported via MPI in some, still to be defined, client topology, it is possible to report each set of ODU termination resources as an ODU TTP within the ODU Topology of Figure 1 and to use either the inter-layer lock-id or the transitional link, as described in sections 3.4 and 3.10 of [TE-TOPO], to correlate the access links, in the client topology, with the ODU TTPs, in the ODU topology, to which access link are connected to.

The "external-domain" container allows the MDSC to glue together the ODU Topology provided by the Transport PNC with the information provided by the IP PNC to know which access link is connected with each link/router in the IP domain (e.g., that C-R1 is connected with the access link terminating on S3-1 LTP in the ODU Topology).

Further details about how the MDSC can glue together the access link information will be added in a future version of this document.

### 3.2. Service Configuration

#### 3.2.1. ODU Transit Service

In this case, the access links are configured as ODU Link, as described in section 3.1.1 above.

As described in section 4.3.1 of [TNBI-UseCases], the MDSC needs to setup an ODU2 trail, supporting an IP link, between C-R1 and C-R3.

From the topology information described in section 3.1.1 above, the MDSC can know that C-R1 is attached to the access link terminating on S3-1 LTP in the ODU Topology and that C-R3 is attached to the access link terminating on S6-2 LTP in the ODU Topology.

Based on the assumption 1) in section 1.1, MDSC would then request the Transport PNC to setup an ODU2 (Transit Segment) Tunnel between S3-1 and S6-2 LTPs:

- o Source and Destination TTPs are not specified (since it is a Transit Tunnel)
- o Ingress and egress points are indicated in the explicit-route-objects of the primary path:
  - o The first element of the explicit-route-objects references the access link terminating on S3-1 LTP
  - o Last element of the explicit-route-objects references the access link terminating on S6-2 LTP

The configuration of the timeslots used by the ODU2 connection within the transport network domain (i.e., on the internal links) is a matter of the Transport PNC and its interactions with the physical network elements and therefore is outside the scope of this document.

However, the configuration of the timeslots used by the ODU2 connection at the edge of the transport network domain (i.e., on the

access links) needs to take into account not only the timeslots available on the physical nodes at the edge of the transport network domain (e.g., S3 and S6) but also on the devices, outside of the transport network domain, connected through these access links (e.g., C-R1 and C-R3).

Based on the assumption 2) in section 1.1, the MDSC, when requesting the Transport PNC to setup the (Transit Segment) ODU2 Tunnel, it would also configure the timeslots to be used on the access links. The MDSC can know the timeslots which are available on the edge OTN Node (e.g., S3 and S6) from the OTN Topology information exposed by the Transport PNC at the MPI as well as the timeslots which are available on the devices outside of the transport network domain (e.g., C-R1 and C-R3), by means which are outside the scope of this document.

The Transport PNC performs path computation and sets up the ODU2 cross-connections within the physical nodes S3, S5 and S6, as shown in section 4.3.1 of [TNBI-UseCases].

The Transport PNC reports the status of the created ODU2 (Transit Segment) Tunnel and its path within the ODU Topology as shown in Figure 2 below:

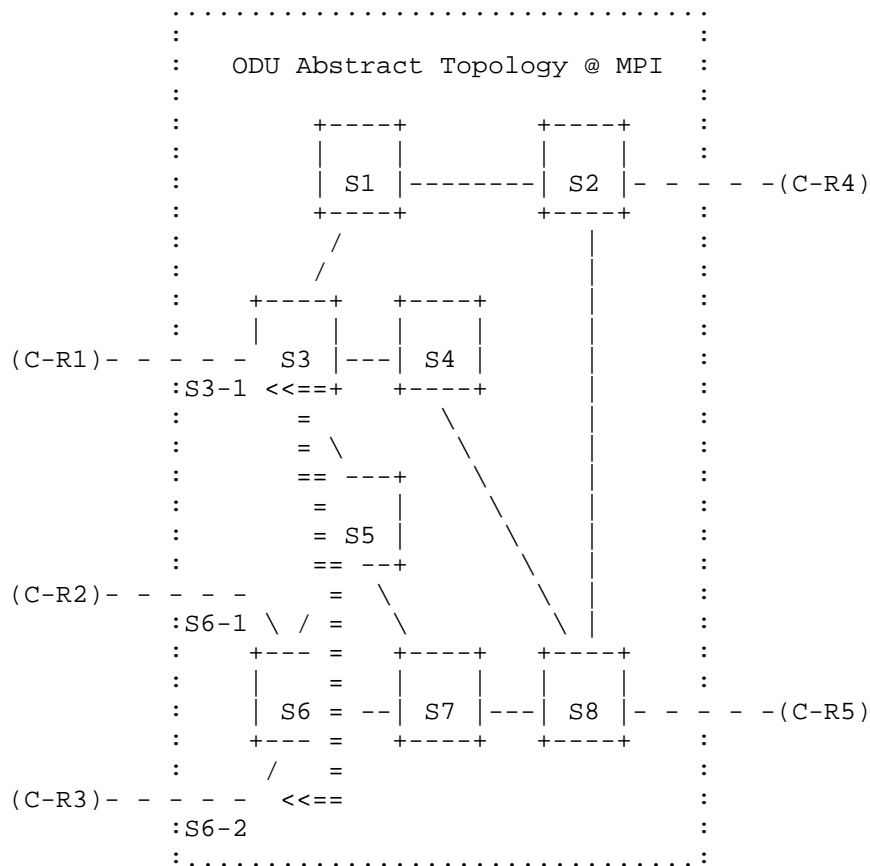


Figure 2 ODU2 Transit Tunnel

### 3.2.2. EPL over ODU Service

As described in section 4.3.2 of [TNBI-UseCases], the MDSC needs to setup an EPL service between C-R1 and C-R3 supported by an ODU2 end-to-end connection between S3 and S6.

As described in section 3.1.1 above, it is not clear in this case how the Ethernet access links between the transport network and the IP router, are reported by the PNC to the MDSC.

If the 10GE physical links are not reported as ODU links within the ODU topology information, described in section 3.1.1 above, than the MDSC will not have sufficient information to know that C-R1 and C-R3 are attached to nodes S3 and S6.



Assuming that the MDSC knows how C-R1 and C-R3 are attached to the transport network, the MDSC would request the Transport PNC to setup an ODU2 end-to-end Tunnel between S3 and S6.

This ODU Tunnel is setup between two TTPs of nodes S3 and S6. In case nodes S3 and S6 support more than one TTP, the MDSC should decide which TTP to use.

As discussed in section 3.1.1, depending on the different hardware implementations of the physical nodes S3 and S6, not all the access links can be connected to all the TTPs. The MDSC should therefore not only select the optimal TTP but also a TTP that would allow the Tunnel to be used by the service.

It is assumed that in case node S3 or node S6 supports only one TTP, this TTP can be accessed by all the access links.

Once the ODU2 Tunnel setup has been requested, unless there is a one-to-one relationship between the S3 and S6 TTPs and the Ethernet access links toward C-R1 and C-R3 (as in the case, described in section 3.1.1, where the Ethernet access links reside on different/dedicated access card such that the ODU2 tunnel can only carry the Ethernet traffic from the only Ethernet access link on the same access card where the ODU2 tunnel is terminated), the MDSC also needs to request the setup of an EPL service from the access links on S3 and S6, attached to C-R1 and C-R3, and this ODU2 Tunnel.

### 3.2.3. OTN Client Private Line Service

As described in section 3.1.1 above, it is not clear in this case how the access links (e.g., the STM-N access links) between the transport network and the IP router, are reported by the PNC to the MDSC.

As described in section 4.3.3 of [TNBI-UseCases], the MDSC needs to setup an STM-64 Private Link service between C-R1 and C-R3 supported by an ODU2 end-to-end connection between S3 and S6.

The same issues, as described in section 3.2.2, apply here:

- o the MDSC needs to understand that C-R1 and C-R3 are connected, through STM-64 access links, with S3 and S6
- o the MDSC needs to understand which TTPs in S3 and S6 can be accessed by these access links
- o the MDSC needs to configure the private line service from these access links through the ODU2 tunnel

#### 3.2.4. EVPL over ODU Service

As described in section 3.1.1 above, it is not clear in this case how the Ethernet access links between the transport network and the IP router, are reported by the PNC to the MDSC.

As described in section 4.3.3 of [TNBI-UseCases], the MDSC needs to setup EVPL services between C-R1 and C-R3, as well as between C-R1 and C-R4, supported by ODU0 end-to-end connections between S3 and S6 as well as between S3 and S2.

The same issues, as described in section 3.2.2, apply here:

- o the MDSC needs to understand that C-R1, C-R3 and C-R4 are connected, through the Ethernet access links, with S3, S6 and S2
- o the MDSC needs to understand which TTPs in S3, S6 and S2 can be accessed by these access links
- o the MDSC needs to configure the EVPL services from these access links through the ODU0 tunnels

In addition, the MDSC needs to get the information that the access links on S3, S6 and S2 are capable to support EVPL (rather than just EPL) as well as to coordinate the VLAN configuration, for each EVPL service, on these access links (this is a similar issue as the timeslot configuration on access links discussed in section 3.2.1 below).

### 4. Topology Abstraction: detailed JSON examples

#### 4.1. ODU White Topology Abstraction

Section 3.1.1 describes how the Transport PNC can provide a white topology abstraction to the MDSC via the MPI. Figure 1 is an example of such ODU Topology.

This section provides the detailed JSON code describing how this ODU Topology is reported by the PNC, using the [TE-TOPO] and [OTN-TOPO] YANG models at the MPI.

JSON code "use-case-1-topology-01.json" has been provided at in the appendix of this document.

## 5. Service Configuration: detailed JSON examples

### 5.1. ODU Transit Service

Section 3.2.1 describes how the MDSC can request a Transport PNC, via the MPI, to setup an ODU2 transit service over an ODU Topology described in section 3.1.1.

This section provides the detailed JSON code describing how the setup of this ODU2 transit service can be requested by the MDSC, using the [TE-TUNNEL] and [OTN-TUNNEL] YANG models at the MPI.

JSON code "use-case-1-odu2-service-01.json" has been provided at in the appendix of this document.

## 6. Security Considerations

This section is for further study

## 7. IANA Considerations

This document requires no IANA actions.

## 8. Conclusions

This section is for further study

## 9. References

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## 10. Acknowledgments

The authors would like to thank all members of the Transport NBI Design Team involved in the definition of use cases, gap analysis and guidelines for using the IETF YANG models at the Northbound Interface (NBI) of a Transport SDN Controller.

The authors would like to thank Xian Zhang, Anurag Sharma, Sergio Belotti, Tara Cummings, Michael Scharf, Karthik Sethuraman, Oscar Gonzalez de Dios, Hans Bjursrom and Italo Busi for having initiated the work on gap analysis for transport NBI and having provided foundations work for the development of this document.

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## Appendix A. Validating a JSON fragment against a YANG Model

The objective is to have a tool that allows validating whether a piece of JSON code is compliant with a YANG model without using a client/server.

### A.1. DSDL-based approach

The idea is to generate a JSON driver file (JTOX) from YANG, then use it to translate JSON to XML and validate it against the DSDL schemas, as shown in Figure 3.

Useful link: <https://github.com/mbj4668/pyang/wiki/XmlJson>

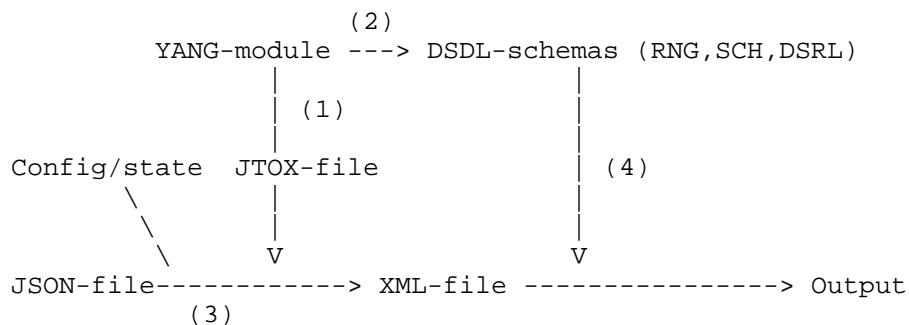


Figure 3 - DSDL-based approach for JSON code validation

In order to allow the use of comments following the convention defined in section 2 without impacting the validation process, these comments will be automatically removed from the JSON-file that will be validate.

### A.2. Why not using a XSD-based approach

This approach has been analyzed and discarded because no longer supported by pyang.

The idea is to convert YANG to XSD, JSON to XML and validate it against the XSD, as shown in Figure 4:

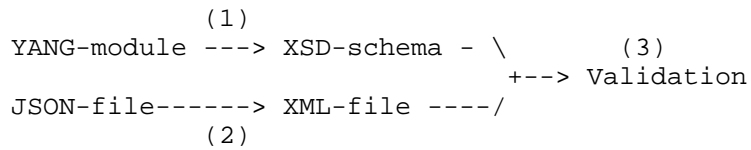


Figure 4 - XSD-based approach for JSON code validation

The pyang support for the XSD output format was deprecated in 1.5 and removed in 1.7.1. However pyang 1.7.1 is necessary to work with YANG 1.1 so the process shown in Figure 4 will stop just at step (1).

#### A.3. JSON Code: use-case-1-topology-01.json

The JSON code for this use case is currently located on GitHub at:

<https://github.com/danielkinguk/transport-nbi/blob/master/Internet-Drafts/Use-Case-1-Analysis/use-case-1-topology-01.json>

#### A.4. JSON Code: use-case-1-topology-01.json

The JSON code for this use case is currently located on GitHub at:

<https://github.com/danielkinguk/transport-nbi/blob/master/Internet-Drafts/Use-Case-1-Analysis/use-case-1-odu2-service-01.json>

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## Abstract

Transport network domains, including Optical Transport Network (OTN) and Wavelength Division Multiplexing (WDM) networks, are typically deployed based on a single vendor or technology platforms. They are often managed using proprietary interfaces to dedicated Element Management Systems (EMS), Network Management Systems (NMS) and increasingly Software Defined Network (SDN) controllers.

A well-defined open interface to each domain management system or controller is required for network operators to facilitate control automation and orchestrate end-to-end services across multi-domain networks. These functions may be enabled using standardized data models (e.g. YANG), and appropriate protocol (e.g., RESTCONF).

This document describes the key use cases and requirements for transport network control and management. It reviews proposed and existing IETF transport network data models, their applicability, and highlights gaps and requirements.

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## 1. Introduction

A common open interface to each domain controller/management system is pre-requisite for network operators to control multi-vendor and multi-domain networks and enable also service provisioning coordination/automation. This can be achieved by using standardized YANG models, used together with an appropriate protocol (e.g., RESTCONF).

This document assumes a reference architecture, including interfaces, based on the Abstraction and Control of Traffic-Engineered Networks (ACTN), defined in [ACTN-Frame].

The focus of the current version is on the MPI (interface between the Multi Domain Service Coordinator (MDSC) and a Physical Network Controller (PNC), controlling a transport network domain).

The relationship between the current IETF YANG models and the type of ACTN interfaces can be found in [ACTN-YANG].

The ONF Technical Recommendations for Functional Requirements for the transport API, may be found in [ONF TR-527]. Furthermore, ONF transport API multi-layer examples may be found in [ONF GitHub].

This document describes use cases that could be used for analyzing the applicability of the existing models defined by the IETF for transport networks

Considerations about the CMI (interface between the Customer Network Controller (CNC) and the MDSC) are for further study.

## 2. Conventions used in this document

For discussion in future revisions of this document.

## 3. Use Case 1: Single-domain with single-layer

### 3.1. Reference Network

The current considerations discussed in this document are based on the following reference networks:

- single transport domain: OTN network



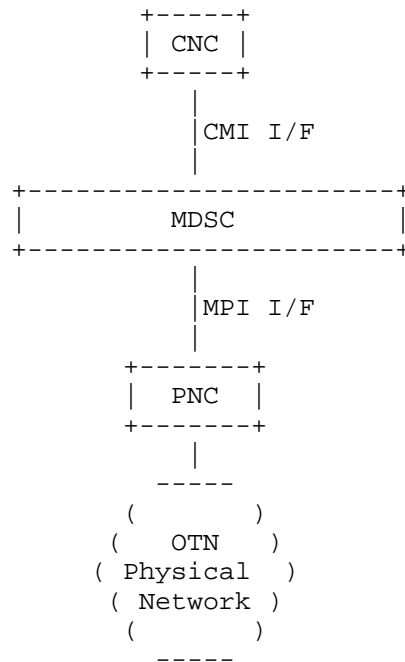


Figure 2 Controlling Hierarchy for Use Case 1

The mapping of the client IP traffic on the physical link between the routers and the transport network is made in the IP routers only and is not controlled by the transport PNC and is transparent to the transport nodes.

The control plane architecture follows the ACTN architecture and framework document [ACTN-Frame]. The Client Controller act as a client with respect to the Multi-Domain Service Coordinator (MDSC) via the Controller-MDSC Interface (CMI). The MDSC is connected to a plurality of Physical Network Controllers (PNCs), one for each domain, via a MDSC-PNC Interface (MPI). Each PNC is responsible only for the control of its domain and the MDSC is the only entity capable of multi-domain functionalities as well as of managing the inter-domain links. The key point of the whole ACTN framework is detaching the network and service control from the underlying technology and help the customer express the network as desired by business needs. Therefore, care must be taken to keep minimal dependency on the CMI (or no dependency at all) with respect to the network domain technologies. The MPI instead requires some specialization according to the domain technology.

In this section, we address the case of an IP and a Transport PNC having respectively an IP a Transport MPI. The interface within the scope of this document is the Transport MPI while the IP Network MPI is out of its scope and considerations about the CMI are for further study.

### 3.2. Topology Abstractions

There are multiple methods to abstract a network topology. This document assumes the abstraction method defined in [RFC7926]:

Abstraction is the process of applying policy to the available TE information within a domain, to produce selective information that represents the potential ability to connect across the domain. Thus, abstraction does not necessarily offer all possible connectivity options, but presents a general view of potential connectivity according to the policies that determine how the domain's administrator wants to allow the domain resources to be used.

[TE-Topo] describes a YANG base model for TE topology without any technology specific parameters. Moreover, it defines how to abstract for TE-network topologies.

[ACTN-Abstraction] provides the context of topology abstraction in the ACTN architecture and discusses a few alternatives for the abstraction methods for both packet and optical networks. This is an important consideration since the choice of the abstraction method impacts protocol design and the information it carries. According to [ACTN-Abstraction], there are three types of topology:

- o White topology: This is a case where the Physical Network Controller (PNC) provides the actual network topology to the Multi-domain Service Coordinator (MDSC) without any hiding or filtering. In this case, the MDSC has the full knowledge of the underlying network topology.
- o Black topology: The entire domain network is abstracted as a single virtual node with the access/egress links without disclosing any node internal connectivity information.
- o Grey topology: This abstraction level is between black topology and white topology from a granularity point of view. This is abstraction of TE tunnels for all pairs of border nodes. We may further differentiate from a perspective of how to abstract internal TE resources between the pairs of border nodes:

- Grey topology type A: border nodes with a TE links between them in a full mesh fashion.
- Grey topology type B: border nodes with some internal abstracted nodes and abstracted links.

For single-domain with single-layer use-case, the white topology may be disseminated from the PNC to the MDSC in most cases. There may be some exception to this in the case where the underlay network may have complex optical parameters, which do not warrant the distribution of such details to the MDSC. In such case, the topology disseminated from the PNC to the MDSC may not have the entire TE information but a streamlined TE information. This case would incur another action from the MDSC's standpoint when provisioning a path. The MDSC may make a path compute request to the PNC to verify the feasibility of the estimated path before making the final provisioning request to the PNC, as outlined in [Path-Compute].

Topology abstraction for the CMI is for further study (to be addressed in future revisions of this document).

### 3.3. Service Configuration

In the following use cases, the Multi Domain Service Coordinator (MDSC) needs to be capable to request service connectivity from the transport Physical Network Controller (PNC) to support IP routers connectivity. The type of services could depend of the type of physical links (e.g. OTN link, ETH link or SDH link) between the routers and transport network.

As described in section 3.1.1, the control of different adaptations inside IP routers, C-Ri (PKT -> foo) and C-Rj (foo -> PKT), are assumed to be performed by means that are not under the control of, and not visible to, transport PNC. Therefore, these mechanisms are outside the scope of this document.

#### 3.3.1. ODU Transit

This use case assumes that the physical link interconnecting IP routers and transport network is an OTN link.

The physical/optical interconnection is supposed to be a pre-configured and not exposed via MPI to MDSC.

If we consider the case of a 10Gb IP link between C-R1 to C-R3, we need to instantiate an ODU2 end-to-end connection between C-R1 and C-R3, crossing transport nodes S3, S5, and S6.

The traffic flow between C-R1 and C-R3 can be summarized as:

C-R1 (PKT -> ODU2), S3 (ODU2), S5 (ODU2), S6 (ODU2),  
C-R3 (ODU2 -> PKT)

The MDSC should be capable via MPI interface to request the setup of ODU2 transit service with enough information that can permit transport PNC to instantiate and control the ODU2 segment through nodes S3, S5, S6.

### 3.3.2. EPL over ODU

This use case assumes that the physical link interconnecting IP routers and transport network is an Ethernet link.

If we consider the case of a 10Gb IP link between C-R1 to C-R3, we need to instantiate an EPL service between C-R1 and C-R3 supported by an ODU2 end-to-end connection between S3 and S6, crossing transport node S5.

The traffic flow between C-R1 and C-R3 can be summarized as:

C-R1 (PKT -> ETH), S3 (ETH -> ODU2), S5 (ODU2),  
S6 (ODU2 -> ETH), C-R3 (ETH-> PKT)

The MDSC should be capable via MPI i/f to request the setup of EPL service with enough information that can permit transport PNC to instantiate and control the ODU2 end-to-end connection through nodes S3, S5, S6, as well as the adaptation functions inside S3 and S6: S3&S6 (ETH -> ODU2) and S5&S6 (ODU2 -> ETH).

### 3.3.3. Other OTN Client Services

[ITU-T G.709-2016] defines mappings of different client layers into ODU. Most of them are used to provide Private Line services over an OTN transport network supporting a variety of types of physical access links (e.g., Ethernet, SDH STM-N, Fibre Channel, InfiniBand,).

This use case assumes that the physical links interconnecting IP routers and transport network are any one of these possible options.

If we consider the case of a 10Gb IP link between C-R1 to C-R3 using SDH physical links, we need to instantiate an STM-64 Private Line service between C-R1 and C-R3 supported by an ODU2 end-to-end connection between S3 and S6, crossing transport node S5.



The traffic flow between C-R1 and C-R3 can be summarized as:

C-R1 (PKT -> STM-64), S3 (STM-64 -> ODU2), S5 (ODU2),  
S6 (ODU2 -> STM-64), C-R3 (STM-64 -> PKT)

The MDSC should be capable via MPI i/f to request the setup of an STM-64 Private Line service with enough information that can permit transport PNC to instantiate and control the ODU2 end-to-end connection through nodes S3, S5, S6, as well as the adaptation functions inside S3 and S6: S3&S6 (STM-64 -> ODU2) and S9&S3 (STM-64 -> PKT).

#### 3.3.4. EVPL over ODU

For future revision.

#### 3.3.5. EVPLAN and EVPTree Services

For future revision.

#### 3.3.6. Virtual Network Services

For future revision.

#### 3.4. Multi-functional Access Links

For future revision.

#### 3.5. Protection Scenarios

The MDSC needs to be capable to request the transport PNC to configure protection when requesting the setup of the connectivity services described in section 3.3.

[Editor's note (for DT discussion):] Should we describe only protection or also restoration scenarios?

Since in this use case it is assumed that switching is performed only in one layer, the OTN ODU layer, for all the services defined in section 3.3, protection can only be provided at that same layer.

Resiliency mechanisms on the access link are considered outside the scope of this use case.

[Editor's note (for DT discussion):] I think that scenarios with access link resiliency could be seen as being multi-domain and/or multi-layer. For further discussion with DT members.

### 3.5.1. Linear Protection

It is possible to protect any service defined in section 3.3 from failures within the OTN transport domain by configuring a linear protection group, as defined in [ITU-T G.808.1], in the data plane between node S3 and node S6.

[Editor's note:] Check for IETF references about protection definitions.

The OTN linear protection group can be configured to operate as 1+1 unidirectional, 1+1 bidirectional (to check) or 1:n bidirectional, as defined in [ITU-T G.808.1] and [ITU-T G.873.1].

[Editor's note (for DT discussion):] The most common protection mechanism used in OTN networks is 1+1 unidirectional. Should we consider also the other cases?

In these scenarios, a working transport entity and a protection transport entity, as defined in [ITU-T G.808.1], should be configured in the data plane:

Working transport entity: S3 -> S5 -> S6

Protection transport entity: S3 -> S4 -> S6 -> S7 -> S6

Requirements about how the MDSC could be capable to request the transport PNC to configure the protection group are for further study.

[Editor's note:] Need to discuss whether MDSC should decide that linear protection is needed and whether it should be 1+1 or 1:1 or whether the transport PNC can take this decision based on other information provided by MDSC (or whether both options are possible).

The Transport PNC should be capable to report to the MDSC which is the active transport entity, as defined in [ITU-T G.808.1], in the data plane.

Given the fast dynamic of protection switching operations in the data plane (50ms recovery time), this reporting is not expected to be in real-time.

It is also worth noting that with unidirectional protection switching, e.g., 1+1 unidirectional, the active transport entity may be different in the two directions.

#### 4. Use Case 2: Single-domain with multi-layer

For future revision.

#### 5. Use Case 3: Multi-domain with single-layer

For future revision.

#### 6. Use Case 4: Multi-domain and multi-layer

For future revision.

#### 7. Security Considerations

For further study.

#### 8. IANA Considerations

This document requires no IANA actions.

#### 9. References

##### 9.1. Normative References

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[ONF GitHub] ONF Open Transport (SNOWMASS)  
<https://github.com/OpenNetworkingFoundation/Snowmass-ONFOpenTransport>

## 10. Acknowledgments

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## Abstract

Transport network domains, including Optical Transport Network (OTN) and Wavelength Division Multiplexing (WDM) networks, are typically deployed based on a single vendor or technology platforms. They are often managed using proprietary interfaces to dedicated Element Management Systems (EMS), Network Management Systems (NMS) and increasingly Software Defined Network (SDN) controllers.

A well-defined open interface to each domain management system or controller is required for network operators to facilitate control automation and orchestrate end-to-end services across multi-domain networks. These functions may be enabled using standardized data models (e.g. YANG), and appropriate protocol (e.g., RESTCONF).

This document describes the key use cases and requirements for transport network control and management. It reviews proposed and existing IETF transport network data models, their applicability, and highlights gaps and requirements.

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## 1. Introduction

Transport of packet services are critical for a wide-range of applications and services, including: data center and LAN interconnects, Internet service backhauling, mobile backhaul and enterprise Carrier Ethernet Services. These services are typically setup using stovepipe NMS and EMS platforms, often requiring propriety management platforms and legacy management interfaces. A clear goal of operators will be to automate setup of transport services across multiple transport technology domains.

A common open interface (API) to each domain controller and or management system is pre-requisite for network operators to control multi-vendor and multi-domain networks and enable also service provisioning coordination/automation. This can be achieved by using standardized YANG models, used together with an appropriate protocol (e.g., [RESTCONF]).

This document describes key use cases for analyzing the applicability of the existing models defined by the IETF for transport networks. The intention of this document is to become an applicability statement that provides detailed descriptions of how IETF transport models are applied to solve the described use cases and requirements.

### 1.1. Scope of this document

This document assumes a reference architecture, including interfaces, based on the Abstraction and Control of Traffic-Engineered Networks (ACTN), defined in [ACTN-Frame]

The focus of this document is on the MPI (interface between the Multi Domain Service Coordinator (MDSC) and a Physical Network Controller (PNC), controlling a transport network domain).

The relationship between the current IETF YANG models and the type of ACTN interfaces can be found in [ACTN-YANG].

The ONF Technical Recommendations for Functional Requirements for the transport API in [ONF TR-527] and the ONF transport API multi-layer examples in [ONF GitHub] have been considered as an input for this work.

Considerations about the CMI (interface between the Customer Network Controller (CNC) and the MDSC) are outside the scope of this document.

## 2. Terminology

E-LINE: Ethernet Line

EPL: Ethernet Private Line

EVPL: Ethernet Virtual Private Line

OTH: Optical Network Hierarchy

OTN: Optical Transport Network

## 3. Conventions used in this document

### 3.1. Topology and traffic flow processing

The traffic flow between different nodes is specified as an ordered list of nodes, separated with commas, indicating within the brackets the processing within each node:

```
<node> (<processing>){, <node> (<processing>)}
```

The order represents the order of traffic flow being forwarded through the network.

The processing can be either an adaptation of a client layer into a server layer "(client -> server)" or switching at a given layer "([switching])". Multi-layer switching is indicated by two layer switching with client/server adaptation: "([client] -> [server])".

For example, the following traffic flow:

```
C-R1 (|PKT| -> ODU2), S3 (|ODU2|), S5 (|ODU2|), S6 (|ODU2|),  
C-R3 (ODU2 -> |PKT|)
```

Node C-R1 is switching at the packet (PKT) layer and mapping packets into a ODU2 before transmission to node S3. Nodes S3, S5 and S6 are switching at the ODU2 layer: S3 sends the ODU2 traffic to S5 which then sends it to S6 which finally sends to C-R3. Node C-R3 terminates the ODU2 from S6 before switching at the packet (PKT) layer.

The paths of working and protection transport entities are specified as an ordered list of nodes, separated with commas:

```
<node> {, <node>}
```

The order represents the order of traffic flow being forwarded through the network in the forward direction. In case of bidirectional paths, the forward and backward directions are selected arbitrarily, but the convention is consistent between working/protection path pairs as well as across multiple domains.

#### 4. Use Case 1: Single-domain with single-layer

##### 4.1. Reference Network

The current considerations discussed in this document are based on the following reference networks:

- single transport domain: OTN network

##### 4.1.1. Single Transport Domain - OTN Network

As shown in Figure 1 the network physical topology composed of a single-domain transport network providing transport services to an IP network through five access links.

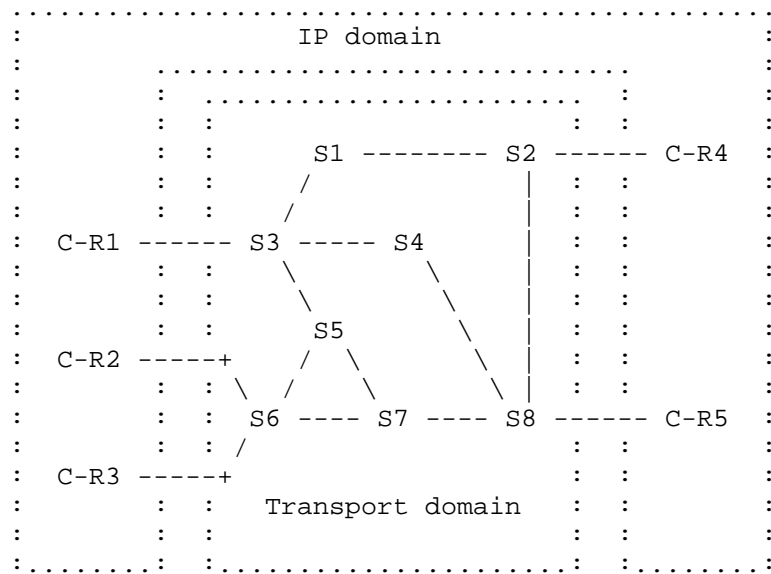


Figure 1 Reference network for Use Case 1

The IP and transport (OTN) domains are respectively composed by five routers C-R1 to C-R5 and by eight ODU switches S1 to S8. The transport domain acts as a transit network providing connectivity for IP layer services.

The behavior of the transport domain is the same whether the ingress or egress service nodes in the IP domain are only attached to the transport domain, or if there are other routers in between the ingress or egress nodes of the IP domain not also attached to the transport domain. In other words, the behavior of the transport network does not depend on whether C-R1, C-R2, ..., C-R5 are PE or P routers for the IP services.

The transport domain control plane architecture follows the ACTN architecture and framework document [ACTN-Framel], and functional components:

- o Customer Network Controller (CNC) act as a client with respect to the Multi-Domain Service Coordinator (MDSC) via the CNC-MDSC Interface (CMI);

- o MDSC is connected to a plurality of Physical Network Controllers (PNCs), one for each domain, via a MDSC-PNC Interface (MPI). Each PNC is responsible only for the control of its domain and the MDSC is the only entity capable of multi-domain functionalities as well as of managing the inter-domain links;

The ACTN framework facilitates the detachment of the network and service control from the underlying technology and help the customer express the network as desired by business needs. Therefore, care must be taken to keep minimal dependency on the CMI (or no dependency at all) with respect to the network domain technologies. The MPI instead requires some specialization according to the domain technology.

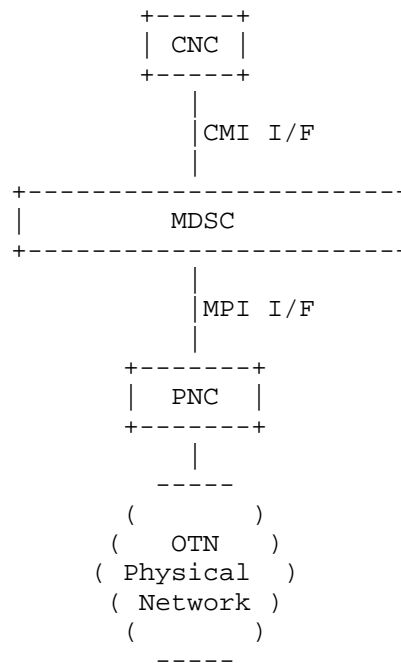


Figure 2 Controlling Hierarchy for Use Case 1

Once the service request is processed by the MDSC the mapping of the client IP traffic between the routers (across the transport network) is made in the IP routers only and is not controlled by the transport PNC, and therefore transparent to the transport nodes.

#### 4.2. Topology Abstractions

Abstraction provides a selective method for representing connectivity information within a domain. There are multiple methods to abstract a network topology. This document assumes the abstraction method defined in [RFC7926]:

"Abstraction is the process of applying policy to the available TE information within a domain, to produce selective information that represents the potential ability to connect across the domain. Thus, abstraction does not necessarily offer all possible connectivity options, but presents a general view of potential connectivity according to the policies that determine how the domain's administrator wants to allow the domain resources to be used."

[TE-Topo] describes a YANG base model for TE topology without any technology specific parameters. Moreover, it defines how to abstract for TE-network topologies.

[ACTN-Frame] provides the context of topology abstraction in the ACTN architecture and discusses a few alternatives for the abstraction methods for both packet and optical networks. This is an important consideration since the choice of the abstraction method impacts protocol design and the information it carries. According to [ACTN-Frame], there are three types of topology:

- o White topology: This is a case where the Physical Network Controller (PNC) provides the actual network topology to the multi-domain Service Coordinator (MDSC) without any hiding or filtering. In this case, the MDSC has the full knowledge of the underlying network topology;
- o Black topology: The entire domain network is abstracted as a single virtual node with the access/egress links without disclosing any node internal connectivity information;
- o Grey topology: This abstraction level is between black topology and white topology from a granularity point of view. This is abstraction of TE tunnels for all pairs of border nodes. We may further differentiate from a perspective of how to abstract internal TE resources between the pairs of border nodes:
  - Grey topology type A: border nodes with a TE links between them in a full mesh fashion;

- Grey topology type B: border nodes with some internal abstracted nodes and abstracted links.

For single-domain with single-layer use-case, the white topology may be disseminated from the PNC to the MDSC in most cases. There may be some exception to this in the case where the underlay network may have complex optical parameters, which do not warrant the distribution of such details to the MDSC. In such case, the topology disseminated from the PNC to the MDSC may not have the entire TE information but a streamlined TE information. This case would incur another action from the MDSC's standpoint when provisioning a path. The MDSC may make a path compute request to the PNC to verify the feasibility of the estimated path before making the final provisioning request to the PNC, as outlined in [Path-Compute].

Topology abstraction for the CMI is for further study (to be addressed in future revisions of this document).

#### 4.3. Service Configuration

In the following use cases, the Multi Domain Service Coordinator (MDSC) needs to be capable to request service connectivity from the transport Physical Network Controller (PNC) to support IP routers connectivity. The type of services could depend of the type of physical links (e.g. OTN link, ETH link or SDH link) between the routers and transport network.

As described in section 4.1.1, the control of different adaptations inside IP routers, C-Ri (PKT -> foo) and C-Rj (foo -> PKT), are assumed to be performed by means that are not under the control of, and not visible to, transport PNC. Therefore, these mechanisms are outside the scope of this document.

##### 4.3.1. ODU Transit

This use case assumes that the physical links interconnecting the IP routers and the transport network are OTN links. The physical/optical interconnection below the ODU layer is supposed to be pre-configured and not exposed at the MPI to the MDSC.

To setup a 10Gb IP link between C-R1 to C-R3, an ODU2 end-to-end data plane connection needs to be created between C-R1 and C-R3, crossing transport nodes S3, S5, and S6.

The traffic flow between C-R1 and C-R3 can be summarized as:

C-R1 (|PKT| -> ODU2), S3 (|ODU2|), S5 (|ODU2|), S6 (|ODU2|),  
C-R3 (ODU2 -> |PKT|)

The MDSC should be capable via the MPI to request the setup of an ODU2 transit service with enough information that enable the transport PNC to instantiate and control the ODU2 data plane connection segment through nodes S3, S5, S6.

#### 4.3.2. EPL over ODU

This use case assumes that the physical links interconnecting the IP routers and the transport network are Ethernet links.

In order to setup a 10Gb IP link between C-R1 to C-R3, an EPL service needs to be created between C-R1 and C-R3, supported by an ODU2 end-to-end connection between S3 and S6, crossing transport node S5.

The traffic flow between C-R1 and C-R3 can be summarized as:

C-R1 (|PKT| -> ETH), S3 (ETH -> |ODU2|), S5 (|ODU2|),  
S6 (|ODU2| -> ETH), C-R3 (ETH-> |PKT|)

The MDSC should be capable via the MPI to request the setup of an EPL service with enough information that can permit the transport PNC to instantiate and control the ODU2 end-to-end data plane connection through nodes S3, S5, S6, as well as the adaptation functions inside S3 and S6: S3&S6 (ETH -> ODU2) and S5&S6 (ODU2 -> ETH).

#### 4.3.3. Other OTN Client Services

[ITU-T G.709-2016] defines mappings of different client layers into ODU. Most of them are used to provide Private Line services over an OTN transport network supporting a variety of types of physical access links (e.g., Ethernet, SDH STM-N, Fibre Channel, InfiniBand, etc.).

This use case assumes that the physical links interconnecting the IP routers and the transport network are any one of these possible options.

In order to setup a 10Gb IP link between C-R1 to C-R3 using, for example STM-64 physical links between the IP routers and the transport network, an STM-64 Private Line service needs to be created between C-R1 and C-R3, supported by an ODU2 end-to-end data plane connection between S3 and S6, crossing transport node S5.



The traffic flow between C-R1 and C-R3 can be summarized as:

```
C-R1 (|PKT| -> STM-64), S3 (STM-64 -> |ODU2|), S5 (|ODU2|),  
S6 (|ODU2| -> STM-64), C-R3 (STM-64 -> |PKT|)
```

The MDSC should be capable via the MPI to request the setup of an STM-64 Private Line service with enough information that can permit the transport PNC to instantiate and control the ODU2 end-to-end connection through nodes S3, S5, S6, as well as the adaptation functions inside S3 and S6: S3&S6 (STM-64 -> ODU2) and S9&S3 (STM-64 -> PKT).

#### 4.3.4. EVPL over ODU

This use case assumes that the physical links interconnecting the IP routers and the transport network are Ethernet links and that different Ethernet services (e.g, EVPL) can share the same physical link using different VLANs.

In order to setup two 1Gb IP links between C-R1 to C-R3 and between C-R1 and C-R4, two EVPL services need to be created, supported by two ODU0 end-to-end connections respectively between S3 and S6, crossing transport node S5, and between S3 and S2, crossing transport node S1.

Since the two EVPL services are sharing the same Ethernet physical link between C-R1 and S3, different VLAN IDs are associated with different EVPL services: for example VLAN IDs 10 and 20 respectively.

The traffic flow between C-R1 and C-R3 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |ODU0|), S5 (|ODU0|),  
S6 (|ODU0| -> VLAN), C-R3 (VLAN -> |PKT|)
```

The traffic flow between C-R1 and C-R4 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |ODU0|), S1 (|ODU0|),  
S2 (|ODU0| -> VLAN), C-R4 (VLAN -> |PKT|)
```

The MDSC should be capable via the MPI to request the setup of these EVPL services with enough information that can permit the transport PNC to instantiate and control the ODU0 end-to-end data plane connections as well as the adaptation functions on the boundary nodes: S3&S2&S6 (VLAN -> ODU0) and S3&S2&S6 (ODU0 -> VLAN).

#### 4.3.5. EVPLAN and EVPTree Services

This use case assumes that the physical links interconnecting the IP routers and the transport network are Ethernet links and that different Ethernet services (e.g, EVPL, EVPLAN and EVPTree) can share the same physical link using different VLANs.

Note - it is assumed that EPLAN and EPTree services can be supported by configuring EVPLAN and EVPTree with port mapping.

In order to setup an IP subnet between C-R1, C-R2, C-R3 and C-R4, an EVPLAN/EVPTree service needs to be created, supported by two ODUFlex end-to-end connections respectively between S3 and S6, crossing transport node S5, and between S3 and S2, crossing transport node S1.

In order to support this EVPLAN/EVPTree service, some Ethernet Bridging capabilities are required on some nodes at the edge of the transport network: for example Ethernet Bridging capabilities can be configured in nodes S3 and S6 but not in node S2.

Since this EVPLAN/EVPTree service can share the same Ethernet physical links between IP routers and transport nodes (e.g., with the EVPL services described in section 4.3.4), a different VLAN ID (e.g., 30) can be associated with this EVPLAN/EVPTree service.

In order to support an EVPTree service instead of an EVPLAN, additional configuration of the Ethernet Bridging capabilities on the nodes at the edge of the transport network is required.

The MAC bridging function in node S3 is needed to select, based on the MAC Destination Address, whether the Ethernet frames from C-R1 should be sent to the ODUFlex terminating on node S6 or to the other ODUFlex terminating on node S2.

The MAC bridging function in node S6 is needed to select, based on the MAC Destination Address, whether the Ethernet frames received from the ODUFlex should be set to C-R2 or C-R3, as well as whether the Ethernet frames received from C-R2 (or C-R3) should be sent to C-R3 (or C-R2) or to the ODUFlex.

For example, the traffic flow between C-R1 and C-R3 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |MAC| -> |ODUFlex|),  
S5 (|ODUFlex|), S6 (|ODUFlex| -> |MAC| -> VLAN),  
C-R3 (VLAN -> |PKT|)
```

The MAC bridging function in node S3 is also needed to select, based on the MAC Destination Address, whether the Ethernet frames one ODUflex should be sent to C-R1 or to the other ODUflex.

For example, the traffic flow between C-R3 and C-R4 can be summarized as:

```
C-R3 (|PKT| -> VLAN), S6 (VLAN -> |MAC| -> |ODUflex|),
S5 (|ODUflex|), S3 (|ODUflex| -> |MAC| -> |ODUflex|),
S1 (|ODUflex|), S2 (|ODUflex| -> VLAN), C-R4 (VLAN -> |PKT|)
```

In node S2 there is no need for any MAC bridging function since all the Ethernet frames received from C-R4 should be sent to the ODUflex toward S3 and viceversa.

The traffic flow between C-R1 and C-R4 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |MAC| -> |ODUflex|),
S1 (|ODUflex|), S2 (|ODUflex| -> VLAN), C-R4 (VLAN -> |PKT|)
```

The MDSC should be capable via the MPI to request the setup of this EVPLAN/EVPTree services with enough information that can permit the transport PNC to instantiate and control the ODUflex end-to-end data plane connections as well as the Ethernet Bridging and adaptation functions on the boundary nodes: S3&S6 (VLAN -> MAC -> ODU2), S3&S6 (ODU2 -> ETH -> VLAN), S2 (VLAN -> ODU2) and S2 (ODU2 -> VLAN).

#### 4.4. Multi-functional Access Links

This use case assumes that some physical links interconnecting the IP routers and the transport network can be configured in different modes, e.g., as OTU2 or STM-64 or 10GE.

This configuration can be done a-priori by means outside the scope of this document. In this case, these links will appear at the MPI either as an ODU Link or as an STM-64 Link or as a 10GE Link (depending on the a-priori configuration) and will be controlled at the MPI as discussed in section 4.3.

It is also possible not to configure these links a-priori and give the control to the MPI to decide, based on the service configuration, how to configure it.

For example, if the physical link between C-R1 and S3 is a multi-functional access link while the physical links between C-R3 and S6 and between C-R4 and S2 are STM-64 and 10GE physical links respectively, it is possible at the MPI to configure either an STM-

64 Private Line service between C-R1 and C-R3 or an EPL service between C-R1 and C-R4.

The traffic flow between C-R1 and C-R3 can be summarized as:

```
C-R1 (|PKT| -> STM-64), S3 (STM-64 -> |ODU2|), S5 (|ODU2|),  
S6 (|ODU2| -> STM-64), C-R3 (STM-64 -> |PKT|)
```

The traffic flow between C-R1 and C-R4 can be summarized as:

```
C-R1 (|PKT| -> ETH), S3 (ETH -> |ODU2|), S1 (|ODU2|),  
S2 (|ODU2| -> ETH), C-R4 (ETH-> |PKT|)
```

The MDSC should be capable via the MPI to request the setup of either service with enough information that can permit the transport PNC to instantiate and control the ODU2 end-to-end data plane connection as well as the adaptation functions inside S3 and S2 or S6.

#### 4.5. Protection Requirements

Protection switching provides a pre-allocated survivability mechanism, typically provided via linear protection methods and would be configured to operate as 1+1 unidirectional (the most common OTN protection method), 1+1 bidirectional or 1:n bidirectional. This ensures fast and simple service survivability.

The MDSC needs to be capable to request the transport PNC to configure protection when requesting the setup of the connectivity services described in section 4.3.

Since in this use case it is assumed that switching within the transport network domain is performed only in one layer, also protection switching within the transport network domain can only be provided at the OTN ODU layer, for all the services defined in section 4.3.

It may be necessary to consider not only protection, but also restoration functions in the future. Restoration methods would provide capability to reroute and restore connectivity traffic around network faults, without the network penalty imposed with dedicated 1+1 protection schemes.

#### 4.5.1. Linear Protection

It is possible to protect any service defined in section 4.3 from failures within the OTN transport domain by configuring OTN linear protection in the data plane between node S3 and node S6.

It is assumed that the OTN linear protection is configured to with 1+1 unidirectional protection switching type, as defined in [ITU-T G.808.1-2014] and [ITU-T G.873.1-2014], as well as in [RFC4427].

In these scenarios, a working transport entity and a protection transport entity, as defined in [ITU-T G.808.1-2014], (or a working LSP and a protection LSP, as defined in [RFC4427]) should be configured in the data plane, for example:

Working transport entity: S3, S5, S6

Protection transport entity: S3, S4, S8, S7, S6

The Transport PNC should be capable to report to the MDSC which is the active transport entity, as defined in [ITU-T G.808.1-2014], in the data plane.

Given the fast dynamic of protection switching operations in the data plane (50ms recovery time), this reporting is not expected to be in real-time.

It is also worth noting that with unidirectional protection switching, e.g., 1+1 unidirectional protection switching, the active transport entity may be different in the two directions.

### 5. Use Case 2: Single-domain with multi-layer

#### 5.1. Reference Network

The current considerations discussed in this document are based on the following reference network:

- single transport domain: OTN and OCh multi-layer network

In this use case, the same reference network shown in Figure 1 is considered. The only difference is that all the transport nodes are capable to switch in the ODU as well as in the OCh layer.

All the physical links within the transport network are therefore assumed to be OCh links. Therefore, with the exception of the access

links, no ODU internal link exists before an OCh end-to-end data plane connection is created within the network.

The controlling hierarchy is the same as described in Figure 2.

The interface within the scope of this document is the Transport MPI which should be capable to control both the OTN and OCh layers.

## 5.2. Topology Abstractions

A grey topology type B abstraction is assumed: abstract nodes and links exposed at the MPI corresponds 1:1 with the physical nodes and links controlled by the PNC but the PNC abstracts/hides at least some optical parameters to be used within the OCh layer.

## 5.3. Service Configuration

The same service scenarios, as described in section 4.3, are also applicable to these use cases with the only difference that end-to-end OCh data plane connections will need to be setup before ODU data plane connections.

## 6. Use Case 3: Multi-domain with single-layer

### 6.1. Reference Network

In this section we focus on a multi-domain reference network with homogeneous technologies:

- multiple transport domains: OTN networks

Figure 3 shows the network physical topology composed of three transport network domains providing transport services to an IP customer network through eight access links:

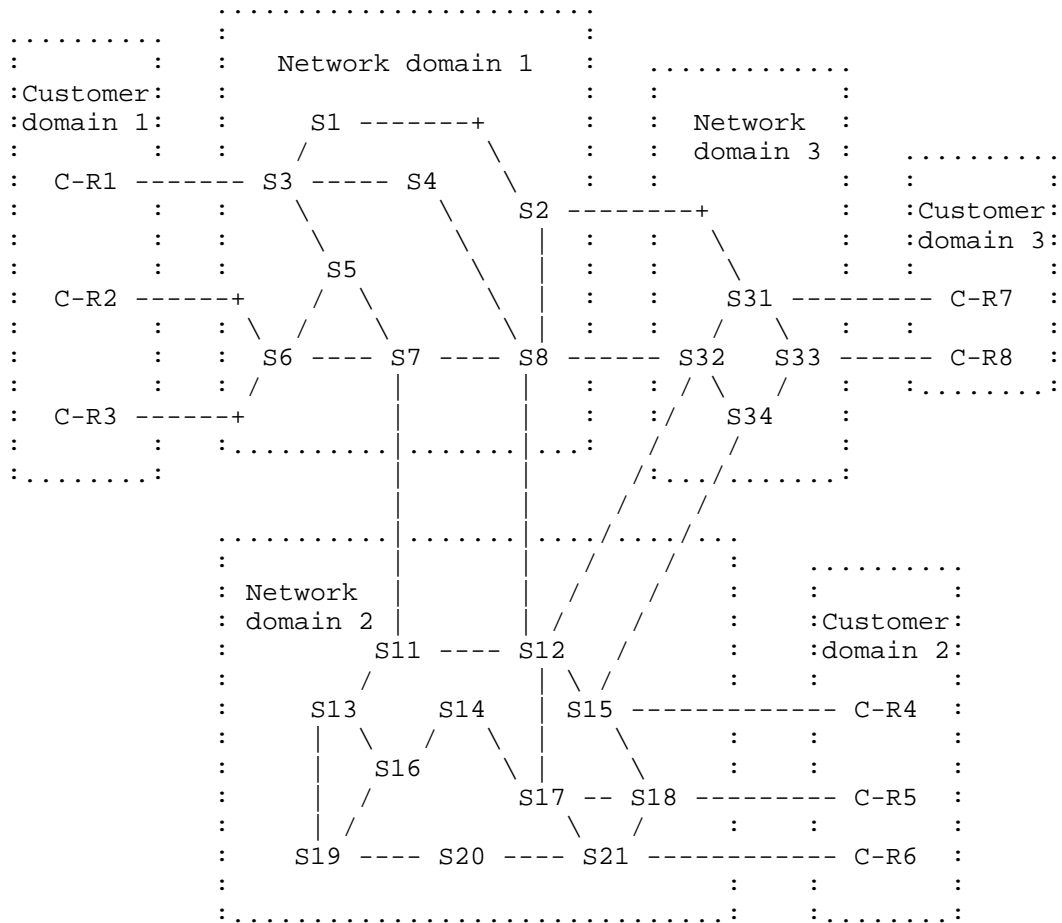


Figure 3 Reference network for Use Case 3

It is worth noting that the network domain 1 is identical to the transport domain shown in Figure 1.

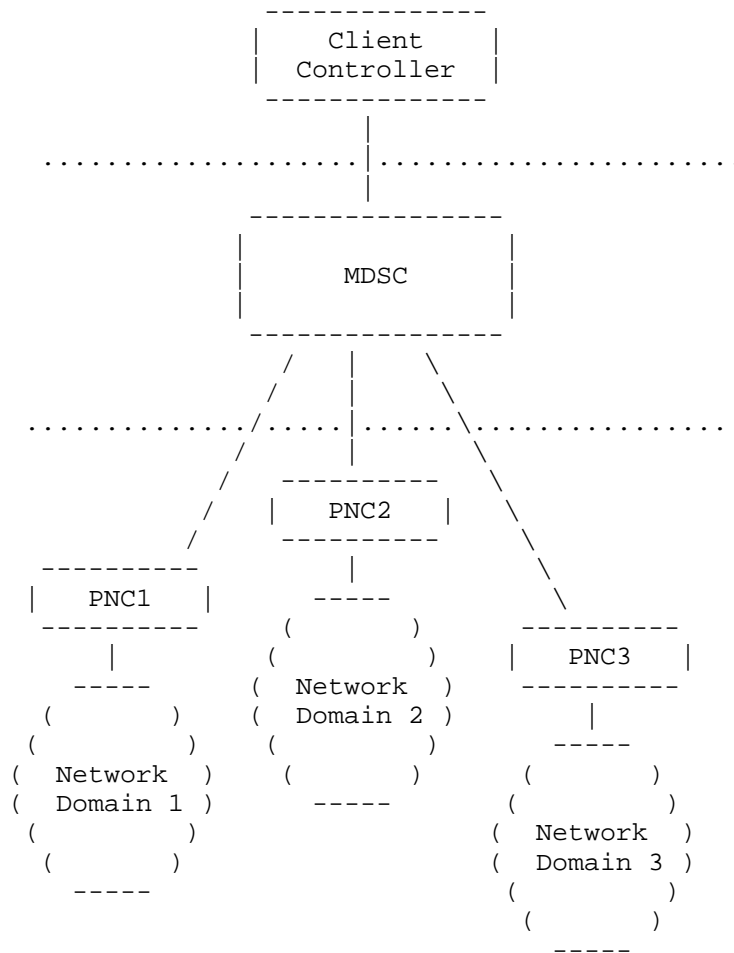


Figure 4 Controlling Hierarchy for Use Case 3

In this section we address the case where the CNC controls the customer IP network and requests transport connectivity among IP routers, via the CMI, to an MDSC which coordinates, via three MPIs, the control of a multi-domain transport network through three PNCs.

The interfaces within the scope of this document are the three MPIs while the interface between the CNC and the IP routers is out of its scope and considerations about the CMI are outside the scope of this document.



## 6.2. Topology Abstractions

Each PNC should provide the MDSC a topology abstraction of the domain's network topology.

Each PNC provides topology abstraction of its own domain topology independently from each other and therefore it is possible that different PNCs provide different types of topology abstractions.

As an example, we can assume that:

- o PNC1 provides a white topology abstraction (likewise use case 1 described in section 4.2)
- o PNC2 provides a type A grey topology abstraction
- o PNC3 provides a type B grey topology abstraction, with two abstract nodes (AN31 and AN32). They abstract respectively nodes S31+S33 and nodes S32+S34. At the MPI, only the abstract nodes should be reported: the mapping between the abstract nodes (AN31 and AN32) and the physical nodes (S31, S32, S33 and S34) should be done internally by the PNC.

The MDSC should be capable to glue together these different abstract topologies to build its own view of the multi-domain network topology. This might require proper administrative configuration or other mechanisms (to be defined/analysed).

## 6.3. Service Configuration

In the following use cases, it is assumed that the CNC is capable to request service connectivity from the MDSC to support IP routers connectivity.

The same service scenarios, as described in section 4.3, are also application to this use cases with the only difference that the two IP routers to be interconnected are attached to transport nodes which belong to different PNCs domains and are under the control of the CNC.

Likewise, the service scenarios in section 4.3, the type of services could depend of the type of physical links (e.g. OTN link, ETH link or SDH link) between the customer's routers and the multi-domain transport network and the configuration of the different adaptations inside IP routers is performed by means that are outside the scope of this document because not under control of and not visible to the MDSC nor to the PNCs. It is assumed that the CNC is capable to

request the proper configuration of the different adaptation functions inside the customer's IP routers, by means which are outside the scope of this document.

It is also assumed that the CNC is capable via the CMI to request the MDSC the setup of these services with enough information that enable the MDSC to coordinate the different PNCs to instantiate and control the ODU2 data plane connection through nodes S3, S1, S2, S31, S33, S34, S15 and S18, as well as the adaptation functions inside nodes S3 and S18, when needed.

As described in section 6.2, the MDSC should have its own view of the end-to-end network topology and use it for its own path computation to understand that it needs to coordinate with PNC1, PNC2 and PNC3 the setup and control of a multi-domain ODU2 data plane connection.

#### 6.3.1. ODU Transit

In order to setup a 10Gb IP link between C-R1 and C-R5, an ODU2 end-to-end data plane connection needs be created between C-R1 and C-R5, crossing transport nodes S3, S1, S2, S31, S33, S34, S15 and S18 which belong to different PNC domains.

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> ODU2), S3 (|ODU2|), S1 (|ODU2|), S2 (|ODU2|),
S31 (|ODU2|), S33 (|ODU2|), S34 (|ODU2|),
S15 (|ODU2|), S18 (|ODU2|), C-R5 (ODU2 -> |PKT|)
```

#### 6.3.2. EPL over ODU

In order to setup a 10Gb IP link between C-R1 and C-R5, an EPL service needs to be created between C-R1 and C-R5, supported by an ODU2 end-to-end data plane connection between transport nodes S3 and S18, crossing transport nodes S1, S2, S31, S33, S34 and S15 which belong to different PNC domains.

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> ETH), S3 (ETH -> |ODU2|), S1 (|ODU2|),
S2 (|ODU2|), S31 (|ODU2|), S33 (|ODU2|), S34 (|ODU2|),
S15 (|ODU2|), S18 (|ODU2| -> ETH), C-R5 (ETH -> |PKT|)
```

### 6.3.3. Other OTN Client Services

In order to setup a 10Gb IP link between C-R1 and C-R5 using, for example SDH physical links between the IP routers and the transport network, an STM-64 Private Line service needs to be created between C-R1 and C-R5, supported by ODU2 end-to-end data plane connection between transport nodes S3 and S18, crossing transport nodes S1, S2, S31, S33, S34 and S15 which belong to different PNC domains.

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> STM-64), S3 (STM-64 -> |ODU2|), S1 (|ODU2|),  
S2 (|ODU2|), S31 (|ODU2|), S33 (|ODU2|), S34 (|ODU2|),  
S15 (|ODU2|), S18 (|ODU2| -> STM-64), C-R5 (STM-64 -> |PKT|)
```

### 6.3.4. EVPL over ODU

In order to setup two 1Gb IP links between C-R1 to C-R3 and between C-R1 and C-R5, two EVPL services need to be created, supported by two ODU0 end-to-end connections respectively between S3 and S6, crossing transport node S5, and between S3 and S18, crossing transport nodes S1, S2, S31, S33, S34 and S15 which belong to different PNC domains.

The VLAN configuration on the access links is the same as described in section 4.3.4.

The traffic flow between C-R1 and C-R3 is the same as described in section 4.3.4.

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |ODU2|), S1 (|ODU2|),  
S2 (|ODU2|), S31 (|ODU2|), S33 (|ODU2|), S34 (|ODU2|),  
S15 (|ODU2|), S18 (|ODU2| -> VLAN), C-R5 (VLAN -> |PKT|)
```

### 6.3.5. EVPLAN and EVPTree Services

In order to setup an IP subnet between C-R1, C-R2, C-R3 and C-R7, an EVPLAN/EVPTree service needs to be created, supported by two ODUflex end-to-end connections respectively between S3 and S6, crossing transport node S5, and between S3 and S18, crossing transport nodes S1, S2, S31, S33, S34 and S15 which belong to different PNC domains.

The VLAN configuration on the access links is the same as described in section 4.3.5.

The configuration of the Ethernet Bridging capabilities on nodes S3 and S6 is the same as described in section 4.3.5 while the configuration on node S18 similar to the configuration of node S2 described in section 4.3.5.

The traffic flow between C-R1 and C-R3 is the same as described in section 4.3.5.

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> VLAN), S3 (VLAN -> |MAC| -> |ODUflex|),
S1 (|ODUflex|), S2 (|ODUflex|), S31 (|ODUflex|),
S33 (|ODUflex|), S34 (|ODUflex|),
S15 (|ODUflex|), S18 (|ODUflex| -> VLAN), C-R5 (VLAN -> |PKT|)
```

#### 6.4. Multi-functional Access Links

The same considerations of section 4.4 apply with the only difference that the ODU data plane connections could be setup across multiple PNC domains.

For example, if the physical link between C-R1 and S3 is a multi-functional access link while the physical links between C-R7 and S31 and between C-R5 and S18 are STM-64 and 10GE physical links respectively, it is possible to configure either an STM-64 Private Line service between C-R1 and C-R7 or an EPL service between C-R1 and C-R5.

The traffic flow between C-R1 and C-R7 can be summarized as:

```
C-R1 (|PKT| -> STM-64), S3 (STM-64 -> |ODU2|), S1 (|ODU2|),
S2 (|ODU2|), S31 (|ODU2| -> STM-64), C-R3 (STM-64 -> |PKT|)
```

The traffic flow between C-R1 and C-R5 can be summarized as:

```
C-R1 (|PKT| -> ETH), S3 (ETH -> |ODU2|), S1 (|ODU2|),
S2 (|ODU2|), S31 (|ODU2|), S33 (|ODU2|), S34 (|ODU2|),
S15 (|ODU2|), S18 (|ODU2| -> ETH), C-R5 (ETH -> |PKT|)
```

#### 6.5. Protection Scenarios

The MDSC needs to be capable to coordinate different PNCs to configure protection switching when requesting the setup of the connectivity services described in section 6.3.

Since in this use case it is assumed that switching within the transport network domain is performed only in one layer, also

protection switching within the transport network domain can only be provided at the OTN ODU layer, for all the services defined in section 6.3.

#### 6.5.1. Linear Protection (end-to-end)

In order to protect any service defined in section 6.3 from failures within the OTN multi-domain transport network, the MDSC should be capable to coordinate different PNCs to configure and control OTN linear protection in the data plane between nodes S3 and node S18.

The considerations in section 4.5.1 are also applicable here with the only difference that MDSC needs to coordinate with different PNCs the setup and control of the OTN linear protection as well as of the working and protection transport entities (working and protection LSPs).

Two cases can be considered.

In one case, the working and protection transport entities pass through the same PNC domains:

Working transport entity: S3, S1, S2,  
S31, S33, S34,  
S15, S18

Protection transport entity: S3, S4, S8,  
S32,  
S12, S17, S18

In another case, the working and protection transport entities can pass through different PNC domains:

Working transport entity: S3, S5, S7,  
S11, S12, S17, S18

Protection transport entity: S3, S1, S2,  
S31, S33, S34,  
S15, S18

#### 6.5.2. Segmented Protection

In order to protect any service defined in section 6.3 from failures within the OTN multi-domain transport network, the MDSC should be capable to request each PNC to configure OTN intra-domain protection when requesting the setup of the ODU2 data plane connection segment.

If linear protection is used within a domain, the considerations in section 4.5.1 are also applicable here only for the PNC controlling the domain where intra-domain linear protection is provided.

If PNC1 provides linear protection, the working and protection transport entities could be:

Working transport entity: S3, S1, S2

Protection transport entity: S3, S4, S8, S2

If PNC2 provides linear protection, the working and protection transport entities could be:

Working transport entity: S15, S18

Protection transport entity: S15, S12, S17, S18

If PNC3 provides linear protection, the working and protection transport entities could be:

Working transport entity: S31, S33, S34

Protection transport entity: S31, S32, S34

## 7. Use Case 4: Multi-domain and multi-layer

### 7.1. Reference Network

The current considerations discussed in this document are based on the following reference network:

- multiple transport domains: OTN and OCh multi-layer networks

In this use case, the reference network shown in Figure 3 is used. The only difference is that all the transport nodes are capable to switch either in the ODU or in the OCh layer.

All the physical links within each transport network domain are therefore assumed to be OCh links, while the inter-domain links are assumed to be ODU links as described in section 6.1 (multi-domain with single layer - OTN network).

Therefore, with the exception of the access and inter-domain links, no ODU link exists within each domain before an OCh single-domain end-to-end data plane connection is created within the network.

The controlling hierarchy is the same as described in Figure 4.

The interfaces within the scope of this document are the three MPIs which should be capable to control both the OTN and OCh layers within each PNC domain.

## 7.2. Topology Abstractions

Each PNC should provide the MDSC a topology abstraction of its own network topology as described in section 5.2.

As an example, it is assumed that:

- o PNC1 provides a type A grey topology abstraction (likewise in use case 2 described in section 5.2)
- o PNC2 provides a type B grey topology abstraction (likewise in use case 3 described in section 6.2)
- o PNC3 provides a type B grey topology abstraction with two abstract nodes, likewise in use case 3 described in section 6.2, and hiding at least some optical parameters to be used within the OCh layer, likewise in use case 2 described in section 5.2.

## 7.3. Service Configuration

The same service scenarios, as described in section 6.3, are also applicable to these use cases with the only difference that single-domain end-to-end OCh data plane connections needs to be setup before ODU data plane connections.

## 8. Security Considerations

Typically, OTN networks ensure a high level of security and data privacy through hard partitioning of traffic onto isolated circuits.

There may be additional security considerations applied to specific use cases, but common security considerations do exist and these must be considered for controlling underlying infrastructure to deliver transport services:

- o use of RESCONF and the need to reuse security between RESTCONF components;
- o use of authentication and policy to govern which transport services may be requested by the user or application;

- o how secure and isolated connectivity may also be requested as an element of a service and mapped down to the OTN level.

## 9. IANA Considerations

This document requires no IANA actions.

## 10. References

### 10.1. Normative References

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<https://github.com/OpenNetworkingFoundation/Snowmass-ONFOpenTransport>

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YANG data model for Flexi-Grid media-channels  
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## Abstract

This document defines a YANG model for managing flexi-grid optical  
media channels, complementing the information provided by the  
flexi-grid TED model.  
It is also grounded on other defined YANG abstract models.

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## 1. Introduction

Transport networks are evolving from current DWDM systems towards  
elastic optical networks, based on flexi-grid transmission and  
switching technologies [RFC7698]. Such technology aims at increasing  
both transport network scalability and flexibility, allowing the  
optimization of bandwidth usage.

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While [I-D.draft-vergara-ccamp-flexigrid-yang] focuses on flexi-grid objects such as nodes, transponders and links, this document presents a YANG model for the flexi-grid media-channel. This YANG module defines the whole path from a source transponder or node to the destination through a number of intermediate nodes in the flexi-grid network.

This document identifies the flexi-grid media-channel components, parameters and their values, characterizes the features and the performances of the flexi-grid elements. An application example is provided towards the end of the document to better understand their utility.

## 2. Conventions used in this document

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

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

In this document, the characters ">>" preceding an indented line(s) indicates a compliance requirement statement using the key words listed above. This convention aids reviewers in quickly identifying or finding the explicit compliance requirements of this RFC.

## 3. Flexi-grid media-channel overview

The present model defines a flexi-grid media-channel mainly composed of:

- source address
- source flexi-grid port
- source flexi-grid transponder
- destination address
- destination flexi-grid port
- destination flexi-grid transponder
- A list of links that defines the path
- Other optical attributes

Each path can be a media-channel (only defined by source and destination node) or a network media-channel (additionally needs source and destination transponders). Therefore, all the attributes are optional to support both situations.

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 This is achieved by a combination of the traffic engineering tunnel attributes explained in [I-D.draft-ietf-teas-yang-te] and augments when necessary. For instance, source address, source flexi-grid transponder, destination address and destination flexi-grid transponder attributes are directly taken from tunnel, whereas other attributes such as source flexi-grid port, destination flexi-grid port are defined, as they are specific for flexi-grid.

#### 4. Example of use

In order to explain how this model is used, we provide the following example. An optical network usually has multiple transponders, switches (nodes) and links between them. Figure 1 shows a simple topology, where two physical paths interconnect two optical transponders.

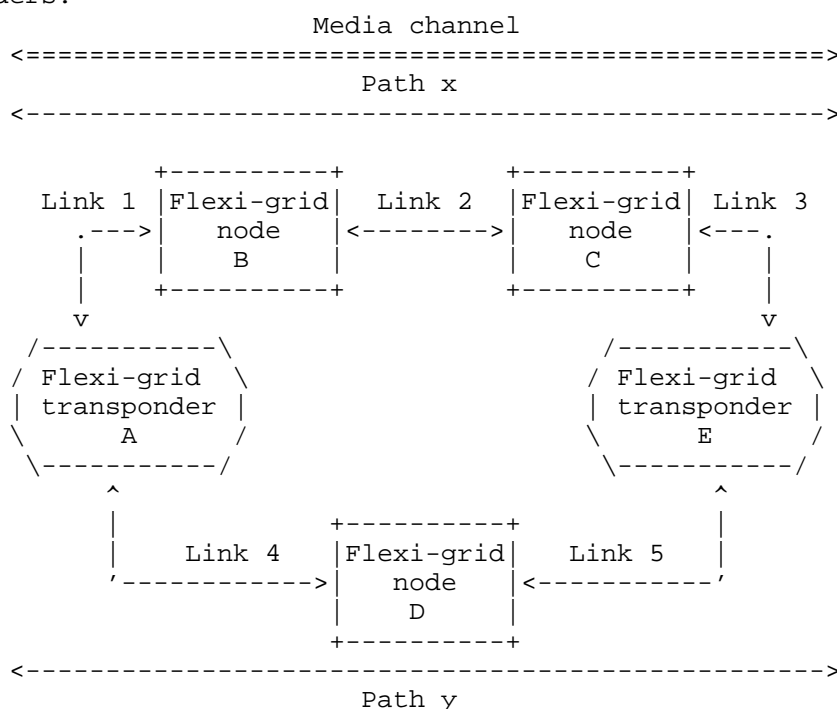


Figure 1. Topology example.

After the nodes, links and transponders have been defined using [I-D.draft-vergara-ccamp-flexigrid-yang], we can configure the media-channel from the information we have stored in the flexi-grid TED, by querying which elements are available, and planning the resources that have to be provided on each situation. Note that every element in the flexi-grid TED has a reference, and this is the way in which they are called in the media-channel.

1. Depending on the case, it is possible to define either the source and destination node ports, or the source and destination node and transponder. In our case, we would define a network media channel, with source transponder A and source node B, and destination transponder E and destination node C. Thus, we are going to follow path x.
2. Then, for each link in the path x, we indicate which channel we are going to use, providing information about the slots, and what nodes are connected.
3. Finally, the flexi-grid TED has to be updated with each element usage status each time a media channel is created or torn down.

## 5. Media Channel YANG Model

### 5.1. YANG Model - Tree

```
module: ietf-flexi-grid-media-channel
  augment /te:te/te:tunnels/te:tunnel/te:config:
    +--rw source-port?          fg-ted:flexi-grid-node-port-ref
    +--rw destination-port?     fg-ted:flexi-grid-node-port-ref
    +--rw effective-freq-slot
      +--rw N?   int32
      +--rw M?   int32
  augment /te:te/te:tunnels/te:tunnel/te:state:
    +--ro source-port?          fg-ted:flexi-grid-node-port-ref
    +--ro destination-port?     fg-ted:flexi-grid-node-port-ref
    +--ro effective-freq-slot
      +--ro N?   int32
      +--ro M?   int32
  augment /te:te/te:lsps-state/te:lsp:
    +--ro N?   int32
    +--ro M?   int32
    +--ro source-port?          fg-ted:flexi-grid-node-port-ref
    +--ro destination-port?     fg-ted:flexi-grid-node-port-ref
    +--ro link?                 fg-ted:flexi-grid-link-ref
    +--ro bidirectional?       boolean
```



```
<CODE BEGINS> file "ietf-flexi-grid-media-channel@2017-07-03.yang"
module ietf-flexi-grid-media-channel {
  yang-version 1.1;

  namespace
    "urn:ietf:params:xml:ns:yang:ietf-flexi-grid-media-channel";
  prefix "fg-mc";

  import ietf-flexi-grid-ted {
    prefix "fg-ted";
  }

  import ietf-te {
    prefix "te";
  }

  import ietf-network {
    prefix "nd";
  }
  organization
    "IETF CCAMP Working Group";
  contact
    "Editor: Jorge Lopez de Vergara
      <jorge.lopez_vergara@uam.es>";

  description
    "This module contains a collection of YANG definitions for
    a Flexi-Grid media channel.

    Copyright (c) 2017 IETF Trust and the persons identified as
    authors of the code. All rights reserved.

    Redistribution and use in source and binary forms, with or
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    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 2017-07-03 {
    description
      "version 0.";

    reference
      "RFC XXX: A Yang Data Model for Flexi-Grid media-channels";
  }
}
```

```

grouping flexi-grid-media-channel {
  description
    "Media association that represents both the topology
    (i.e., path through the media) and the resource
    (frequency slot) that it occupies. As a topological
    construct, it represents a (effective) frequency slot
    supported by a concatenation of media elements (fibers,
    amplifiers, filters, switching matrices...). This term
    is used to identify the end-to-end physical layer entity
    with its corresponding (one or more) frequency slots
    local at each link filters.";
  reference "rfc7698";
  leaf source-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Source port";
  }
  leaf destination-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Destination port";
  }
  container effective-freq-slot {
    description "The effective frequency slot is an attribute
    of a media channel and, being a frequency slot, it is
    described by its nominal central frequency and slot
    width";
    reference "rfc7698";
    leaf N {
      type int32;
      description
        "Is used to determine the Nominal Central
        Frequency. The set of nominal central frequencies
        can be built using the following expression:
          
$$f = 193.1 \text{ THz} + n \times 0.00625 \text{ THz},$$

        where 193.1 THz is ITU-T ''anchor frequency'' for
        transmission over the C band, n is a positive or
        negative integer including 0.";
      reference "rfc7698";
    }
    leaf M {
      type int32;
      description
        "Is used to determine the slot width. A slot width
        is constrained to be M x SWG (that is, M x 12.5 GHz),
        where M is an integer greater than or equal to 1.";
      reference "rfc7698";
    }
  }
}

```

```

grouping link-channel-attributes {
  description
    "A link channel is one of the concatenated elements of
    the media channel.";
  leaf N {
    type int32;
    description
      "Is used to determine the Nominal Central Frequency.
      The set of nominal central frequencies can be built
      using the following expression:
       $f = 193.1 \text{ THz} + n \times 0.00625 \text{ THz}$ ,
      where 193.1 THz is ITU-T ''anchor frequency'' for
      transmission over the C band, n is a positive or
      negative integer including 0.";
    reference "rfc7698";
  }
  leaf M {
    type int32;
    description
      "Is used to determine the slot width. A slot
      width is constrained to be M x SWG (that is,
      M x 12.5 GHz), where M is an integer greater than
      or equal to 1.";
    reference "rfc7698";
  }
  leaf source-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Source port of the link channel";
  }
  leaf destination-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Destination port of the link channel";
  }
  leaf link {
    type fg-ted:flexi-grid-link-ref;
    description "Link of the link channel";
  }
  leaf bidirectional {
    type boolean;
    description
      "Determines whether the link is bidirectional or
      not";
  }
}

```

```
/* Augment for media-channel */
augment "/te:te/te:tunnels/te:tunnel/te:config" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  description "Augment tunnel with media-channel config";
  uses flexi-grid-media-channel;
}

augment "/te:te/te:tunnels/te:tunnel/te:state" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  uses flexi-grid-media-channel;
  description "Augment tunnel with media-channel state";
}

/* Augment for LSP */
augment "/te:te/te:lsps-state/te:lsp" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  uses link-channel-attributes;
  description "Augment LSP for paths";
}
}

<CODE ENDS>
```

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## 6. Security Considerations

The transport protocol used for sending the managed information MUST support authentication and SHOULD support encryption.

The defined data-model by itself does not create any security implications.

## 7. IANA Considerations

The namespace used in the defined models is currently based on the METRO-HAUL project URI. Future versions of this document could register a URI in the IETF XML registry [RFC3688], as well as in the YANG Module Names registry [RFC6020].

#### 8.1. Normative References

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- [RFC6020] Bjorklund, M., Ed., "YANG - A Data Modeling Language for the Network Configuration Protocol (NETCONF)", RFC 6020, October 2010.
- [RFC3688] Mealling, M., "The IETF XML Registry", BCP 81, RFC 3688, January 2004.

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- [I-D.draft-vergara-ccamp-flexigrid-yang] Lopez de Vergara, J., Perdices, D., Lopez, V., Gonzalez de Dios, O., King, D., Lee, Y., Galimberti, G., "YANG data model for Flexi-Grid Optical Networks", Internet Draft, draft-vergara-ccamp-flexigrid-yang-04, 2017.
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#### 9. Contributors

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- o Daniel Michaud Vallinoto, Universidad Autonoma de Madrid

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## Abstract

This document defines a YANG model for managing flexi-grid optical  
media channels, complementing the information provided by the  
flexi-grid TED model.

It is also grounded on other defined YANG abstract models.

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## 1. Introduction

Transport networks are evolving from current DWDM systems towards  
elastic optical networks, based on flexi-grid transmission and  
switching technologies [RFC7698]. Such technology aims at increasing  
both transport network scalability and flexibility, allowing the  
optimization of bandwidth usage.

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While [I-D.draft-ietf-ccamp-flexigrid-yang] focuses on flexi-grid objects such as nodes, transponders and links, this document presents a YANG model for the flexi-grid media-channel. This YANG module defines the whole path from a source transponder or node to the destination through a number of intermediate nodes in the flexi-grid network.

This document identifies the flexi-grid media-channel components, parameters and their values, characterizes the features and the performances of the flexi-grid elements. An application example is provided towards the end of the document to better understand their utility.

## 2. Conventions used in this document

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

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

In this document, the characters ">>" preceding an indented line(s) indicates a compliance requirement statement using the key words listed above. This convention aids reviewers in quickly identifying or finding the explicit compliance requirements of this RFC.

## 3. Flexi-grid media-channel overview

The present model defines a flexi-grid media-channel mainly composed of:

- source address
- source flexi-grid port
- source flexi-grid transponder
- destination address
- destination flexi-grid port
- destination flexi-grid transponder
- A list of links that defines the path
- Other optical attributes

Each path can be a media-channel (only defined by source and destination node) or a network media-channel (additionally needs source and destination transponders). Therefore, all the attributes are optional to support both situations.

This is achieved by a combination of the traffic engineering tunnel attributes explained in [I-D.draft-ietf-teas-yang-te] and augments when necessary. For instance, source address, source flexi-grid transponder, destination address and destination flexi-grid transponder attributes are directly taken from tunnel, whereas other attributes such as source flexi-grid port, destination flexi-grid port are defined, as they are specific for flexi-grid.

#### 4. Example of use

In order to explain how this model is used, we provide the following example. An optical network usually has multiple transponders, switches (nodes) and links between them. Figure 1 shows a simple topology, where two physical paths interconnect two optical transponders.

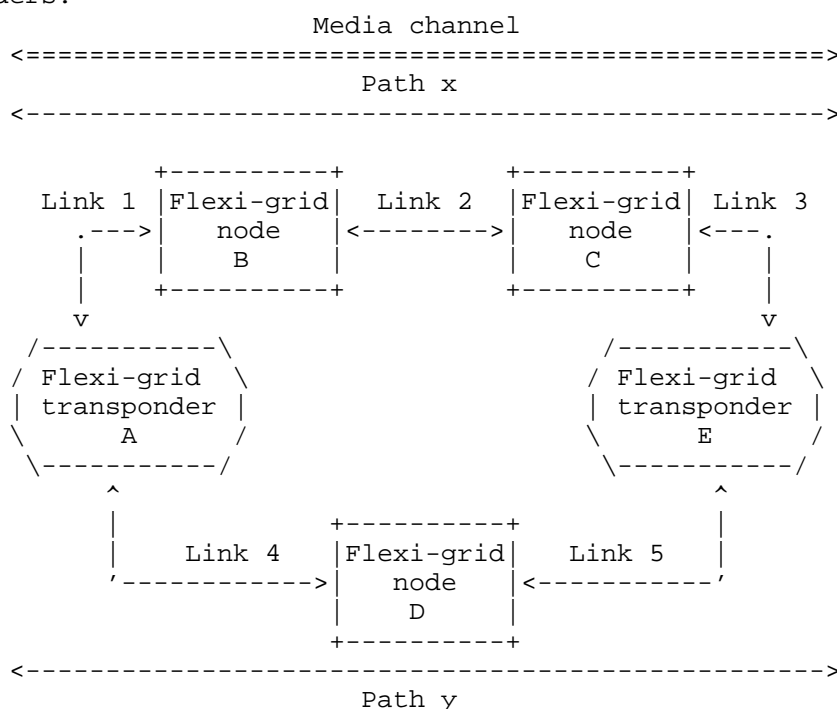


Figure 1. Topology example.

After the nodes, links and transponders have been defined using [I-D.draft-ietf-ccamp-flexigrid-yang], we can configure the media-channel from the information we have stored in the flexi-grid TED, by querying which elements are available, and planning the resources that have to be provided on each situation. Note that every element in the flexi-grid TED has a reference, and this is the way in which they are called in the media-channel.

1. Depending on the case, it is possible to define either the source and destination node ports, or the source and destination node and transponder. In our case, we would define a network media channel, with source transponder A and source node B, and destination transponder E and destination node C. Thus, we are going to follow path x.
2. Then, for each link in the path x, we indicate which channel we are going to use, providing information about the slots, and what nodes are connected.
3. Finally, the flexi-grid TED has to be updated with each element usage status each time a media channel is created or torn down.

## 5. Media Channel YANG Model

### 5.1. YANG Model - Tree

```
module: ietf-flexi-grid-media-channel
  augment /te:te/te:tunnels/te:tunnel:
    +--rw source-port?          fg-ted:flexi-grid-node-port-ref
    +--rw destination-port?     fg-ted:flexi-grid-node-port-ref
    +--rw effective-freq-slot
      +--rw N?   int32
      +--rw M?   int32
  augment /te:te/te:tunnels/te:tunnel/te:state:
    +--ro source-port?          fg-ted:flexi-grid-node-port-ref
    +--ro destination-port?     fg-ted:flexi-grid-node-port-ref
    +--ro effective-freq-slot
      +--ro N?   int32
      +--ro M?   int32
  augment /te:te/te:lsps-state/te:lsp:
    +--ro N?   int32
    +--ro M?   int32
    +--ro source-port?          fg-ted:flexi-grid-node-port-ref
    +--ro destination-port?     fg-ted:flexi-grid-node-port-ref
    +--ro link?                 fg-ted:flexi-grid-link-ref
    +--ro bidirectional?        boolean
```

```
<CODE BEGINS> file "ietf-flexi-grid-media-channel@2018-05-08.yang"

module ietf-flexi-grid-media-channel {
  yang-version 1.1;

  namespace
    "urn:ietf:params:xml:ns:yang:ietf-flexi-grid-media-channel";
  prefix "fg-mc";

  import ietf-flexi-grid-ted {
    prefix "fg-ted";
  }

  import ietf-te {
    prefix "te";
  }

  import ietf-network {
    prefix "nd";
  }

  organization
    "IETF CCAMP Working Group";
  contact
    "Editor: Jorge Lopez de Vergara
      <jorge.lopez_vergara@uam.es>";

  description
    "This module contains a collection of YANG definitions for
    a Flexi-Grid media channel.

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    (http://trustee.ietf.org/license-info).";

  revision 2018-05-08 {
    description
      "version 2.";

    reference
      "RFC XXX: A Yang Data Model for Flexi-Grid media-channels";
  }
}
```

```

grouping flexi-grid-media-channel {
  description
    "Media association that represents both the topology
    (i.e., path through the media) and the resource
    (frequency slot) that it occupies. As a topological
    construct, it represents a (effective) frequency slot
    supported by a concatenation of media elements (fibers,
    amplifiers, filters, switching matrices...). This term
    is used to identify the end-to-end physical layer entity
    with its corresponding (one or more) frequency slots
    local at each link filters.";
  reference "rfc7698";
  leaf source-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Source port";
  }
  leaf destination-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Destination port";
  }
  container effective-freq-slot {
    description "The effective frequency slot is an attribute
    of a media channel and, being a frequency slot, it is
    described by its nominal central frequency and slot
    width";
    reference "rfc7698";
    leaf N {
      type int32;
      description
        "Is used to determine the Nominal Central
        Frequency. The set of nominal central frequencies
        can be built using the following expression:
          
$$f = 193.1 \text{ THz} + n \times 0.00625 \text{ THz},$$

        where 193.1 THz is ITU-T ''anchor frequency'' for
        transmission over the C band, n is a positive or
        negative integer including 0.";
      reference "rfc7698";
    }
    leaf M {
      type int32;
      description
        "Is used to determine the slot width. A slot width
        is constrained to be M x SWG (that is, M x 12.5 GHz),
        where M is an integer greater than or equal to 1.";
      reference "rfc7698";
    }
  }
}

```

```

grouping link-channel-attributes {
  description
    "A link channel is one of the concatenated elements of
    the media channel.";
  leaf N {
    type int32;
    description
      "Is used to determine the Nominal Central Frequency.
      The set of nominal central frequencies can be built
      using the following expression:
       $f = 193.1 \text{ THz} + n \times 0.00625 \text{ THz}$ ,
      where 193.1 THz is ITU-T ''anchor frequency'' for
      transmission over the C band, n is a positive or
      negative integer including 0.";
    reference "rfc7698";
  }
  leaf M {
    type int32;
    description
      "Is used to determine the slot width. A slot
      width is constrained to be M x SWG (that is,
      M x 12.5 GHz), where M is an integer greater than
      or equal to 1.";
    reference "rfc7698";
  }
  leaf source-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Source port of the link channel";
  }
  leaf destination-port {
    type fg-ted:flexi-grid-node-port-ref;
    description "Destination port of the link channel";
  }
  leaf link {
    type fg-ted:flexi-grid-link-ref;
    description "Link of the link channel";
  }
  leaf bidirectional {
    type boolean;
    description
      "Determines whether the link is bidirectional or
      not";
  }
}

```

```
/* Augment for media-channel */
augment "/te:te/te:tunnels/te:tunnel" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  description "Augment tunnel with media-channel config";
  uses flexi-grid-media-channel;
}

augment "/te:te/te:tunnels/te:tunnel/te:state" {
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fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  uses flexi-grid-media-channel;
  description "Augment tunnel with media-channel state";
}

/* Augment for LSP */
augment "/te:te/te:lsps-state/te:lsp" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
    description "Augment only for Flexigrid network.";
  }
  uses link-channel-attributes;
  description "Augment LSP for paths";
}
}

<CODE ENDS>
```



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## Abstract

This document defines a YANG model for managing flexi-grid optical Networks. The model described in this document defines a flexi-grid traffic engineering database. A complementary module is referenced to detail the flexi-grid media channels.

This module is grounded on other defined YANG abstract models.

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## 1. Introduction

Internet-based traffic is dramatically increasing every year. Moreover, such traffic is also becoming more dynamic. Thus, transport networks need to evolve from current DWDM systems towards elastic optical networks, based on flexi-grid transmission and switching technologies [RFC7698]. This technology aims at increasing both transport network scalability and flexibility, allowing the optimization of bandwidth usage.

This document presents a YANG model for flexi-grid objects in the dynamic optical network, including the nodes, transponders and links between them, as well as how such links interconnect nodes and transponders.

The YANG model for flexi-grid networks allows the representation of the flexi-grid optical layer of a network, combined with the underlying physical layer.

This document identifies the flexi-grid components, parameters and their values, characterizes the features and the performances of the flexi-grid elements. An application example is provided towards the end of the document to better understand their utility.

## 2. Conventions used in this document

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

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

In this document, the characters ">>" preceding an indented line(s) indicates a compliance requirement statement using the key words listed above. This convention aids reviewers in quickly identifying or finding the explicit compliance requirements of this RFC.

## 3. Flexi-grid network topology model overview

YANG is a data modeling language used to model configuration data manipulated by the NETCONF protocol. Several YANG models have already been specified for network configurations. For instance, the work in [I-D.draft-ietf-i2rs-yang-network-topo] has proposed a generic YANG model for network/service topologies and inventories. The work in [I-D.draft-ietf-teas-yang-te-topo] presents a data model to represent, retrieve and manipulate Traffic Engineering (TE) Topologies. These models serve as base models that other technology specific models can augment. A YANG model has also been proposed in [I-D.draft-dharini-ccamp-dwdm-if-yang] to manage single channel optical interface parameters of DWDM applications, and in

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[I-D.draft-ietf-ccamp-wson-yang] another model has been specified for the routing and wavelength assignment TE topology in wavelength switched optical networks (WSONs). None of them are specific for flexi-grid technology.

Then, as stated before, we propose a model to describe a flexi-grid topology that is split in two YANG sub-modules:

- o Flexi-grid-TED: In order to be compatible with existing proposals, we augment the definitions contained in [I-D.draft-ietf-i2rs-yang-network-topo] and [I-D.draft-ietf-teas-yang-te-topo], by defining the different elements we can find in a flexi-grid network: a node, a transponder and a link. For that, each of those elements is defined as a container that includes a group of attributes. References to the elements are provided to be later used in the definition of a media channel. It also includes the data types for the type of modulation, the flexi-grid technology, the FEC, etc.
- o Media-channel: This module defines the whole path from a source transponder to the destination through a number of intermediate nodes and links. For this, it takes the information defined before in the flexi-grid TED. This module is described in [ID.draft-vergara-ccamp-flexigrid-media-channel-yang]

The following section provides a detailed view of the first module.

#### 4. Main building blocks of the Flexi-grid TED

This section details the defined YANG module. It is listed below in section 6.

The description of the three main components, flexi-grid-node, flexi-grid-transponder and flexi-grid-link is provided below. flexi-grid-sliceable-transponders are also defined.

```
<flexi-grid-node> ::= <config> <state>
```

```
<flexi-grid-node>: This element designates a node in the network.
```

```
<config> ::= <flexi-grid-node-attributes-config>
```

```
<config>: Contains the configuration of a node.  
<flexi-grid-node-attributes-config> ::= <list-interface>  
<connectivity_matrix>
```

```
<flexi-grid-node-attributes-config>: Contains all the attributes related to the node configuration, such as its interfaces or its management addresses.
```

```
<list-interface> ::= <name> <port-number>
<input-port> <output-port> <description>
<interface-type>
[<numbered-interface> / <unnumbered-interface>]
```

<list-interface>: The list containing all the information of the interfaces.

<name>: Determines the interface name.

<port-number>: Port number of the interface.

<input-port>: Boolean value that defines whether the interface is input or not.

<output-port>: Boolean value that defines whether the interface is output or not.

<description>: Description of the usage of the interface.

<interface-type>: Determines if the interface is numbered or unnumbered.

```
<numbered-interface> ::= <n-i-ip-address>
<numbered-interface>: An interface with its own IP address.
```

<n-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the IP address of the interface.

```
<unnumbered-interface> ::= <u-i-ip-address>
<label>
```

<unnumbered-interface>: A interface that needs a label to be unique.

<u-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the node IP address, which with the label defines the interface.

<label>: Label that determines the interface, joint with the node IP address.

```
<connectivity-matrix> ::= <connections>
```

<connectivity-matrix>: Determines whether a connection port in/port out exists.

```
<connections> ::= <input-port-id>
<output-port-id>
```



<flexi-grid-transponder>: This item designates a transponder of a node.

<config> ::= <flexi-grid-transponder-attributes-config>

<config>: Contains the configuration of a transponder.

<flexi-grid-transponder-attributes-config> ::=  
<available-operational-mode> <operational-mode>

<flexi-grid-transponder-attributes>: Contains all the attributes related to the transponder.

<available-operational-mode>: It provides a list of the operational modes available at this transponder.

<operational-mode>: Determines the type of operational mode in use.

<state> ::= <flexi-grid-transponder-attributes-config>  
<flexi-grid-transponder-attributes-state>

<state>: Contains the state of a transponder.

<flexi-grid-transponder-attributes-config>: See above.

<flexi-grid-transponder-attributes-state>: Contains the state of a transponder.

<link> ::= <config> <state>

<link>: This element describes all the information of a link.

<config> ::= <flexi-grid-link-attributes-config>

<config>: Contains the configuration of a link.

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    <flexi-grid-link-attributes-config> ::= <technology-type>  
    <available-label-flexi-grid> <N-max> <base-frequency>  
    <nominal-central-frequency-granularity>  
    <slot-width-granularity>

    <flexi-grid-link-attributes>: Contains all the attributes related to the link, such as its unique id, its N value, its latency, etc.

    <link-id>: Unique id of the link.

    <available-label-flexi-grid>: Array of bits that determines, with each bit, the availability of each interface for flexi-grid technology.

    <N-max>: The max value of N in this link, being N the number of slots.

    <base-frequency>: The default central frequency used in the link.

    <nominal-central-frequency-granularity>: It is the spacing between allowed nominal central frequencies and it is set to 6.25 GHz (note: sometimes referred to as 0.00625 THz).

    <slot-width-granularity>: 12.5 GHz, as defined in G.694.1.

<state> ::= <flexi-grid-link-attributes-config>  
<flexi-grid-link-attributes-state>

    <state>: Contains the state of a link.

    <flexi-grid-link-attributes-config>: See above.

    <flexi-grid-link-attributes-state>: Contains all the the information related to the state of a link.

#### 4.1. Formal Syntax

The previous syntax specification uses the augmented Backus-Naur Form (BNF) as described in [RFC5234].

In order to explain how this model is used, we provide the following example. An optical network usually has multiple transponders, switches (nodes) and links between them. Figure 1 shows a simple topology, where two physical paths interconnect two optical transponders.

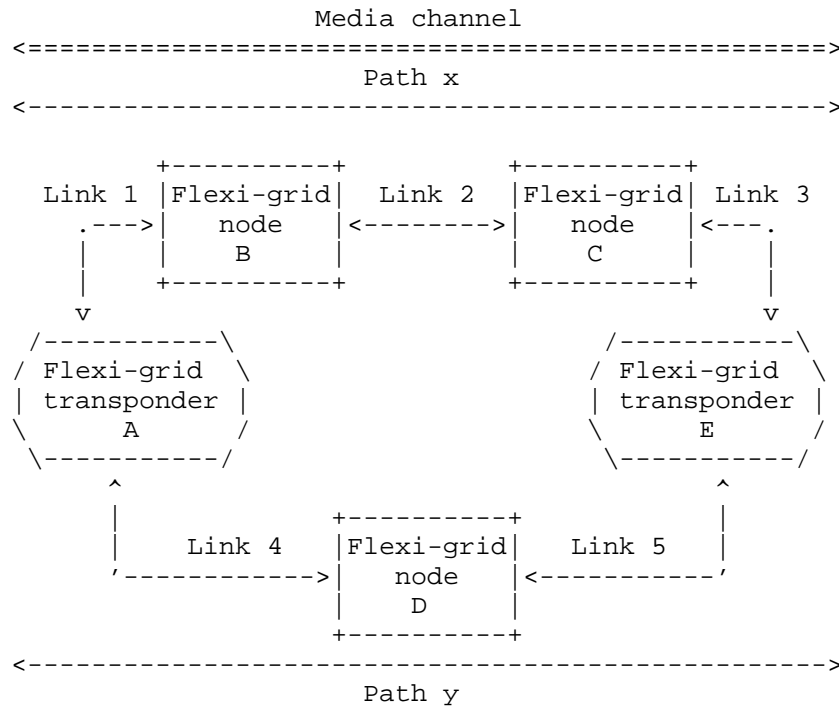


Figure 1. Topology example.

In order to configure a media channel to interconnect transponders A and E, first of all we have to populate the flexi-grid TED YANG model with all elements in the network:

1. We define the transponders A and E, including their FEC type, if enabled, and modulation type. We also provide node identifiers and addresses for the transponders, as well as interfaces included in the transponders. Sliceable transponders can also be defined if needed.
2. We do the same for the nodes B, C and D, providing their identifiers, addresses and interfaces, as well as the internal connectivity matrix between interfaces.
3. Then, we also define the links 1 to 5 that interconnect nodes and transponders, indicating which flexi-grid labels are available. Other information, such as the slot frequency and granularity are also provided.

Next, we can configure the media channel from the information we have stored in the flexi-grid TED, by querying which elements are available, and planning the resources that have to be provided on each situation. Note that every element in the flexi-grid TED has a reference, and this is the way in which they are called in the media channel. We refer to [I-D.draft-vergara-ccamp-flexigrid-media-channel-yang] to complete this example.

## 6. Flexi-grid TED YANG Model

### 6.1. Yang Model - Tree Structure

```

module: ietf-flexi-grid-topology
  augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
    tet-s:te-node-attributes:
      +--ro interfaces* [name]
        +--ro name                string
        +--ro port-number?        uint32
        +--ro input-port?         boolean
        +--ro output-port?        boolean
        +--ro description?        string
        +--ro type?               interface-type
        +--ro numbered-interface
          | +--ro n-i-ip-address?  inet:ip-address
        +--ro unnumbered-interface
          | +--ro u-i-ip-address?  inet:ip-address
          +--ro label?            uint32
  flexi-grid-connectivity-matrix-attributes
    augment /nd:networks/nd:network/nd:node/tet:te/
      tet:te-node-attributes/tet:connectivity-matrices/
      tet:connectivity-matrix:
        +--rw connections* [input-port-id]
          +--rw input-port-id      flexi-grid-node-port-ref
          +--rw output-port-id?    flexi-grid-node-port-ref
  flexi-grid-connectivity-matrix-attributes
    augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
      tet-s:te-node-attributes/tet-s:connectivity-matrices/
      tet-s:connectivity-matrix:
        +--ro connections* [input-port-id]
          +--ro input-port-id      flexi-grid-node-port-ref
          +--ro output-port-id?    flexi-grid-node-port-ref
  flexi-grid-transponder
    augment /nd:networks/nd:network/nd:node/tet:te/
      tet:tunnel-termination-point:
        +--rw available-operational-mode*  operational-mode
        +--rw operational-mode?            operational-mode
  flexi-grid-transponder
    augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
      tet-s:tunnel-termination-point:
        +--ro available-operational-mode*  operational-mode
        +--ro operational-mode?            operational-mode

```

```
<CODE BEGINS> file "ietf-flexi-grid-ted@2017-07-03.yang"
module ietf-flexi-grid-ted {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-flexi-grid-ted";
  prefix "fg-ted";

  import ietf-network {
    prefix "nd";
  }
  import ietf-network-state {
    prefix "nd-s";
  }
  import ietf-network-topology {
    prefix "lnk";
  }
  import ietf-network-topology-state {
    prefix "lnk-s";
  }
  import ietf-te-topology {
    prefix "tet";
  }
  import ietf-te-topology-state {
    prefix "tet-s";
  }
  import ietf-inet-types {
    prefix "inet";
  }
}

organization
  "IETF CCAMP Working Group";

contact
  "Editor: Jorge Lopez de Vergara
    <jorge.lopez_vergara@uam.es>";

description
  "This module contains a collection of YANG definitions for
  a Flexi-Grid Traffic Engineering Database (TED).

  Copyright (c) 2017 IETF Trust and the persons identified as
  authors of the code. All rights reserved."
```

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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 2017-07-03 {  
  description  
    "version 5.";  
  
  reference  
    "RFC XXX: A Yang Data Model for  
    Flexi-Grid Optical Networks ";  
}  
  
/*  
  Typedefs  
*/  
  
typedef operational-mode {  
  type string;  
  description  
    "Vendor-specific 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 recommendation";  
  reference "ITU-T G.698.2 (11/2009) Section 5.3";  
}  
  
typedef interface-type {  
  type enumeration {  
    enum numbered-interface {  
      description "The interface is numbered";  
    }  
    enum unnumbered-interface {  
      description "The interface is unnumbered";  
    }  
  }  
  description  
    "Enumeration that defines if an interface is numbered or  
    unnumbered";  
}
```

```
/*
  Typedef related to references
*/
typedef flexi-grid-link-ref {
  type leafref {
    path
      "/nd:networks/nd:network/lnk:link/lnk:link-id";
  }

  description
    "This type is used by data models that need to reference
    a flexi-grid optical link.";
}

typedef flexi-grid-node-port-ref {
  type leafref {
    path "/nd:networks/nd:network/nd:node/tet:te/"
      +"tet:te-node-attributes/fg-ted:interfaces/"
      +"fg-ted:port-number";
  }
  description
    "This type is used by data models that need to reference
    a flexi-grid port.";
}

typedef flexi-grid-transponder-ref {
  type leafref {
    path "/nd:networks/nd:network/nd:node/tet:te/"
      +"tet:tunnel-termination-point/tet:tunnel-tp-id";
  }
  description
    "This type is used by data models that need to reference
    a trasponder.";
}

/*
  Groupings of attributes
*/
grouping flexi-grid-network-type {
  container flexi-grid-network {
    presence "indicates a flexi-grid optical network";
    description "flexi-grid optical network";
  }
  description "If present, it indicates a flexi-grid
  optical TED network";
}
```

```
grouping flexi-grid-node-attributes {
  description "Set of attributes of an optical node.";

  list interfaces {
    key "name";
    unique "port-number"; // TODO Puerto y TP ID
    description "List of interfaces contained in the node";
    leaf name {
      type string;
      description "Interface name";
    }
    leaf port-number {
      type uint32;
      description "Number of the port used by the interface";
    }

    leaf input-port {
      type boolean;
      description "Determines if the port is an input port";
    }
    leaf output-port {
      type boolean;
      description
        "Determines if the port is an output port";
    }
    leaf description {
      type string;
      description "Description of the interface";
    }
    leaf type {
      type interface-type;
      description "Determines the type of the interface";
    }
    container numbered-interface {
      when "../fg-ted:type =
        'numbered-interface'" {
        description
          "If the interface is a numbered interface";
      }
      description "Container that defines an numbered
        interface with an ip-address";
      leaf n-i-ip-address {
        type inet:ip-address;
        description "IP address of the numbered interface";
      }
    }
  }
}
```



```

    container unnumbered-interface {
      when "../fg-ted:type =
        'unnumbered-interface'" {
        description
          "If the interface is an unnumbered interface";
      }
      description "Container that defines an unnumbered
        interface with an ip-address and a label";
      leaf u-i-ip-address{
        type inet:ip-address;
        description "IP address of the interface";
      }
      leaf label {
        type uint32;
        description "Number as label for the interface";
      }
    }
  }
}

grouping flexi-grid-link-attributes {
  description "Set of attributes of an optical link";
  leaf-list available-label-flexi-grid {
    type bits {
      bit is-available{
        description "Set to 1 when it is available";
      }
    }
  }
  description
    "Array of bits that determines whether a spectral
    slot is available or not.";
}

leaf N-max {
  type int32;
  description "Maximum number of channels available.";
}

leaf base-frequency {
  type decimal64 {
    fraction-digits 5;
  }
  units THz;
  default 193.1;
  description "Default central frequency";
  reference "rfc7698";
}

```

```

    leaf nominal-central-frequency-granularity {
        type decimal64 {
            fraction-digits 5;
        }
        units GHz;
        default 6.25;
        description
            "It is the spacing between allowed nominal central
            frequencies and it is set to 6.25 GHz";
        reference "rfc7698";
    }

    leaf slot-width-granularity {
        type decimal64 {
            fraction-digits 5;
        }
        units GHz;
        default 12.5;
        description "Minimum space between slot widths";
        reference "rfc7698";
    }
}

grouping flexi-grid-transponder-attributes {
    description "Configuration of an optical transponder";
    //TODO Validate attributes
    leaf-list available-operational-mode {
        type operational-mode;
        description "List of all vendor-specific supported
        mode identifiers";
    }

    leaf operational-mode {
        type operational-mode;
        description "Vendor-specific mode identifier";
    }
}

```

```

    grouping flexi-grid-connectivity-matrix-attributes {
      description "Connectivity matrix between the input and
        output ports";
      list connections {
        key "input-port-id";
        leaf input-port-id {
          type flexi-grid-node-port-ref;
          description "Identifier of the input port";
        }
        leaf output-port-id {
          type flexi-grid-node-port-ref;
          description "Identifier of the output port";
        }
      }
      description "List of connections between input and
        output ports";
    }
  }
}

/*
  Augments
*/
augment "/nd:networks/nd:network/nd:network-types" {
  uses flexi-grid-network-type;
  description "Augment network-types including flexi-grid
    topology";
}
augment "/nd-s:networks/nd-s:network/nd-s:network-types" {
  uses flexi-grid-network-type;
  description "Augment network-types including flexi-grid
    topology";
}
augment "/nd:networks/nd:network/lnk:link/tet:te" +
  "/tet:te-link-attributes" {
  when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network" {
    description "Augment only for Flexigrid network.";
  }
  description "Augment link configuration";
  uses flexi-grid-link-attributes;
}

augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te" +
  "/tet-s:te-link-attributes" {
  when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network" {
    description "Augment only for Flexigrid network.";
  }

  description "Augment link state";
  uses flexi-grid-link-attributes;
}

```

```

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augment "/nd:networks/nd:network/nd:node/tet:te" +
  "/tet:te-node-attributes" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }
    uses flexi-grid-node-attributes;
    description "Augment node config with flexi-grid attributes";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te" +
  "/tet-s:te-node-attributes" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-node-attributes;
    description "Augment node state with flexi-grid attributes";
  }
augment "/nd:networks/nd:network/nd:node/tet:te"+
  "/tet:te-node-attributes/tet:connectivity-matrices/" +
  "tet:connectivity-matrix" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-connectivity-matrix-attributes;
    description "Augment node connectivity-matrix for node config";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te"+
  "/tet-s:te-node-attributes/tet-s:connectivity-matrices/" +
  "tet-s:connectivity-matrix" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-connectivity-matrix-attributes;
    description "Augment node connectivity-matrix for node config";
  }

```

```
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augment "/nd:networks/nd:network/nd:node/tet:te"+
  "/tet:tunnel-termination-point" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
      description "Augment only for Flexigrid network.";
    }
    uses flexi-grid-transponder-attributes;
    description "Augment node state with transponder attributes";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te"+
  "/tet-s:tunnel-termination-point" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network"{
      description "Augment only for Flexigrid network.";
    }
    uses flexi-grid-transponder-attributes;
    description "Augment node state with transponder attributes";
  }
}

<CODE ENDS>
```

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The transport protocol used for sending the managed information MUST support authentication and SHOULD support encryption.

The defined data-model by itself does not create any security implications.

## 8. IANA Considerations

The namespace used in the defined models is currently based on the METRO-HAUL project URI. Future versions of this document could register a URI in the IETF XML registry [RFC3688], as well as in the YANG Module Names registry [RFC6020].

## 9. References

### 9.1. Normative References

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## 10. Contributors

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## Abstract

This document defines a YANG model for managing flexi-grid optical  
Networks. The model described in this document defines a flexi-grid  
traffic engineering database. A complementary module is referenced  
to detail the flexi-grid media channels.

This module is grounded on other defined YANG abstract models.

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## 1. Introduction

Internet-based traffic is dramatically increasing every year.  
Moreover, such traffic is also becoming more dynamic. Thus,  
transport networks need to evolve from current DWDM systems towards  
elastic optical networks, based on flexi-grid transmission and  
switching technologies [RFC7698]. This technology aims at increasing  
both transport network scalability and flexibility, allowing the  
optimization of bandwidth usage.

This document presents a YANG model for flexi-grid objects in the dynamic optical network, including the nodes, transponders and links between them, as well as how such links interconnect nodes and transponders.

The YANG model for flexi-grid networks allows the representation of the flexi-grid optical layer of a network, combined with the underlying physical layer.

This document identifies the flexi-grid components, parameters and their values, characterizes the features and the performances of the flexi-grid elements. An application example is provided towards the end of the document to better understand their utility.

## 2. Conventions used in this document

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

In this document, these words will appear with that interpretation only when in ALL CAPS. Lower case uses of these words are not to be interpreted as carrying RFC-2119 significance.

In this document, the characters ">>" preceding an indented line(s) indicates a compliance requirement statement using the key words listed above. This convention aids reviewers in quickly identifying or finding the explicit compliance requirements of this RFC.

## 3. Flexi-grid network topology model overview

YANG is a data modeling language used to model configuration data manipulated by the NETCONF protocol. Several YANG models have already been specified for network configurations. For instance, the work in [I-D.draft-ietf-i2rs-yang-network-topo] has proposed a generic YANG model for network/service topologies and inventories. The work in [I-D.draft-ietf-teas-yang-te-topo] presents a data model to represent, retrieve and manipulate Traffic Engineering (TE) Topologies. These models serve as base models that other technology specific models can augment. A YANG model has also been proposed in [I-D.draft-dharini-ccamp-dwdm-if-yang] to manage single channel optical interface parameters of DWDM applications, and in

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[I-D.draft-ietf-ccamp-wson-yang] another model has been specified for the routing and wavelength assignment TE topology in wavelength switched optical networks (WSONs). None of them are specific for flexi-grid technology.

Then, as stated before, we propose a model to describe a flexi-grid topology that is split in two YANG sub-modules:

- o Flexi-grid-TED: In order to be compatible with existing proposals, we augment the definitions contained in [I-D.draft-ietf-i2rs-yang-network-topo] and [I-D.draft-ietf-teas-yang-te-topo], by defining the different elements we can find in a flexi-grid network: a node, a transponder and a link. For that, each of those elements is defined as a container that includes a group of attributes. References to the elements are provided to be later used in the definition of a media channel. It also includes the data types for the type of modulation, the flexi-grid technology, the FEC, etc.
- o Media-channel: This module defines the whole path from a source transponder to the destination through a number of intermediate nodes and links. For this, it takes the information defined before in the flexi-grid TED. This module is described in [I-D.draft-vergara-ccamp-flexigrid-media-channel-yang]

The following section provides a detailed view of the first module.

#### 4. Main building blocks of the Flexi-grid TED

This section details the defined YANG module. It is listed below in section 6.

The description of the three main components, flexi-grid-node, flexi-grid-transponder and flexi-grid-link is provided below. flexi-grid-sliceable-transponders are also defined.

```
<flexi-grid-node> ::= <config> <state>
```

```
<flexi-grid-node>: This element designates a node in the network.
```

```
<config> ::= <flexi-grid-node-attributes-config>
```

```
<config>: Contains the configuration of a node.  
<flexi-grid-node-attributes-config> ::= <list-interface>  
<connectivity_matrix>
```

```
<flexi-grid-node-attributes-config>: Contains all the attributes related to the node configuration, such as its interfaces or its management addresses.
```

```
<list-interface> ::= <name> <port-number>
<input-port> <output-port> <description>
<interface-type>
[<numbered-interface> / <unnumbered-interface>]
```

<list-interface>: The list containing all the information of the interfaces.

<name>: Determines the interface name.

<port-number>: Port number of the interface.

<input-port>: Boolean value that defines whether the interface is input or not.

<output-port>: Boolean value that defines whether the interface is output or not.

<description>: Description of the usage of the interface.

<interface-type>: Determines if the interface is numbered or unnumbered.

```
<numbered-interface> ::= <n-i-ip-address>
<numbered-interface>: An interface with its own IP address.
```

<n-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the IP address of the interface.

```
<unnumbered-interface> ::= <u-i-ip-address>
<label>
```

<unnumbered-interface>: A interface that needs a label to be unique.

<u-i-ip-address>: Only available if <interface-type> is "numbered-interface". Determines the node IP address, which with the label defines the interface.

<label>: Label that determines the interface, joint with the node IP address.

```
<connectivity-matrix> ::= <connections>
```

<connectivity-matrix>: Determines whether a connection port in/port out exists.

```
<connections> ::= <input-port-id>
<output-port-id>
```

<flexi-grid-transponder>: This item designates a transponder of a node.

<config> ::= <flexi-grid-transponder-attributes-config>

<config>: Contains the configuration of a transponder.

<flexi-grid-transponder-attributes-config> ::=  
<available-operational-mode> <operational-mode>

<flexi-grid-transponder-attributes>: Contains all the attributes related to the transponder.

<available-operational-mode>: It provides a list of the operational modes available at this transponder.

<operational-mode>: Determines the type of operational mode in use.

<state> ::= <flexi-grid-transponder-attributes-config>  
<flexi-grid-transponder-attributes-state>

<state>: Contains the state of a transponder.

<flexi-grid-transponder-attributes-config>: See above.

<flexi-grid-transponder-attributes-state>: Contains the state of a transponder.

<link> ::= <config> <state>

<link>: This element describes all the information of a link.

<config> ::= <flexi-grid-link-attributes-config>

<config>: Contains the configuration of a link.

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    <flexi-grid-link-attributes-config> ::= <technology-type>  
    <available-label-flexi-grid> <N-max> <base-frequency>  
    <nominal-central-frequency-granularity>  
    <slot-width-granularity>

    <flexi-grid-link-attributes>: Contains all the attributes related to the link, such as its unique id, its N value, its latency, etc.

    <link-id>: Unique id of the link.

    <available-label-flexi-grid>: Array of bits that determines, with each bit, the availability of each interface for flexi-grid technology.

    <N-max>: The max value of N in this link, being N the number of slots.

    <base-frequency>: The default central frequency used in the link.

    <nominal-central-frequency-granularity>: It is the spacing between allowed nominal central frequencies and it is set to 6.25 GHz (note: sometimes referred to as 0.00625 THz).

    <slot-width-granularity>: 12.5 GHz, as defined in G.694.1.

<state> ::= <flexi-grid-link-attributes-config>  
<flexi-grid-link-attributes-state>

    <state>: Contains the state of a link.

    <flexi-grid-link-attributes-config>: See above.

    <flexi-grid-link-attributes-state>: Contains all the the information related to the state of a link.

#### 4.1. Formal Syntax

The previous syntax specification uses the augmented Backus-Naur Form (BNF) as described in [RFC5234].



In order to explain how this model is used, we provide the following example. An optical network usually has multiple transponders, switches (nodes) and links between them. Figure 1 shows a simple topology, where two physical paths interconnect two optical transponders.

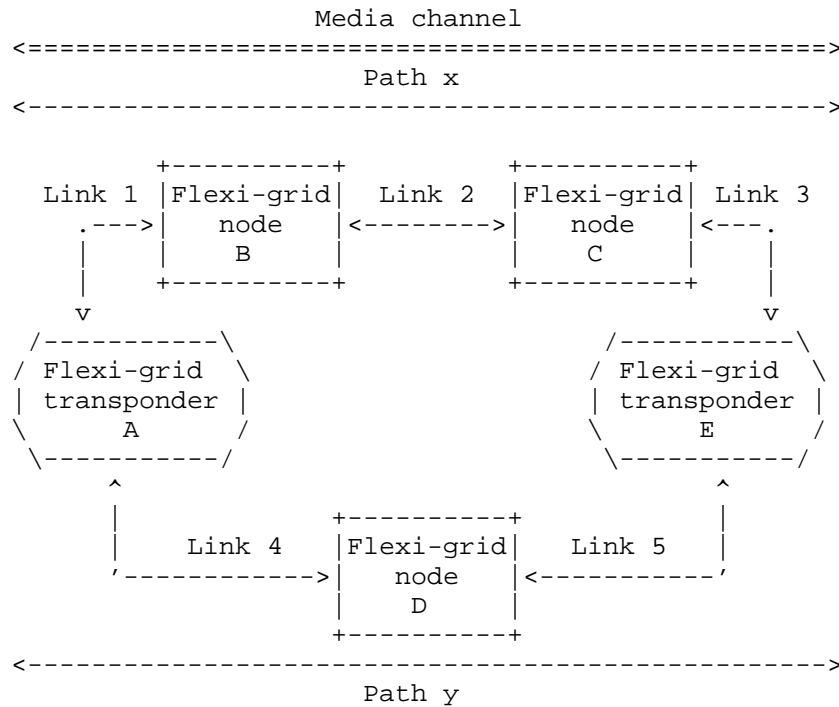


Figure 1. Topology example.

In order to configure a media channel to interconnect transponders A and E, first of all we have to populate the flexi-grid TED YANG model with all elements in the network:

1. We define the transponders A and E, including their FEC type, if enabled, and modulation type. We also provide node identifiers and addresses for the transponders, as well as interfaces included in the transponders. Sliceable transponders can also be defined if needed.
2. We do the same for the nodes B, C and D, providing their identifiers, addresses and interfaces, as well as the internal connectivity matrix between interfaces.
3. Then, we also define the links 1 to 5 that interconnect nodes and transponders, indicating which flexi-grid labels are available. Other information, such as the slot frequency and granularity are also provided.

Next, we can configure the media channel from the information we have stored in the flexi-grid TED, by querying which elements are available, and planning the resources that have to be provided on each situation. Note that every element in the flexi-grid TED has a reference, and this is the way in which they are called in the media channel. We refer to [I-D.draft-vergara-ccamp-flexigrid-media-channel-yang] to complete this example.

## 6. Flexi-grid TED YANG Model

### 6.1. Yang Model - Tree Structure

```

module: ietf-flexi-grid-topology
  augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
    tet-s:te-node-attributes:
      +--ro interfaces* [name]
        +--ro name                string
        +--ro port-number?        uint32
        +--ro input-port?         boolean
        +--ro output-port?        boolean
        +--ro description?        string
        +--ro type?               interface-type
        +--ro numbered-interface
          | +--ro n-i-ip-address?  inet:ip-address
        +--ro unnumbered-interface
          | +--ro u-i-ip-address?  inet:ip-address
          +--ro label?            uint32
  flexi-grid-connectivity-matrix-attributes
    augment /nd:networks/nd:network/nd:node/tet:te/
      tet:te-node-attributes/tet:connectivity-matrices/
      tet:connectivity-matrix:
        +--rw connections* [input-port-id]
          +--rw input-port-id      flexi-grid-node-port-ref
          +--rw output-port-id?    flexi-grid-node-port-ref
  flexi-grid-connectivity-matrix-attributes
    augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
      tet-s:te-node-attributes/tet-s:connectivity-matrices/
      tet-s:connectivity-matrix:
        +--ro connections* [input-port-id]
          +--ro input-port-id      flexi-grid-node-port-ref
          +--ro output-port-id?    flexi-grid-node-port-ref
  flexi-grid-transponder
    augment /nd:networks/nd:network/nd:node/tet:te/
      tet:tunnel-termination-point:
        +--rw available-operational-mode*  operational-mode
        +--rw operational-mode?            operational-mode
  flexi-grid-transponder
    augment /nd-s:networks/nd-s:network/nd-s:node/tet-s:te/
      tet-s:tunnel-termination-point:
        +--ro available-operational-mode*  operational-mode
        +--ro operational-mode?            operational-mode

```

```
<CODE BEGINS> file "ietf-flexi-grid-ted@2018-01-08.yang"
module ietf-flexi-grid-ted {
  yang-version 1.1;

  namespace "urn:ietf:params:xml:ns:yang:ietf-flexi-grid-ted";
  prefix "fg-ted";

  import ietf-network {
    prefix "nd";
  }
  import ietf-network-state {
    prefix "nd-s";
  }
  import ietf-network-topology {
    prefix "lnk";
  }
  import ietf-network-topology-state {
    prefix "lnk-s";
  }
  import ietf-te-topology {
    prefix "tet";
  }
  import ietf-te-topology-state {
    prefix "tet-s";
  }
  import ietf-inet-types {
    prefix "inet";
  }
}

organization
  "IETF CCAMP Working Group";

contact
  "Editor: Jorge Lopez de Vergara
    <jorge.lopez_vergara@uam.es>";
description
  "This module contains a collection of YANG definitions for
  a Flexi-Grid Traffic Engineering Database (TED).

  Copyright (c) 2018 IETF Trust and the persons identified as
  authors of the code. All rights reserved."
```

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```
revision 2018-01-08 {
  description
    "version 5.";

  reference
    "RFC XXX: A Yang Data Model for
    Flexi-Grid Optical Networks ";
}

/*
  Typedefs
*/

typedef operational-mode {
  type string;
  description
    "Vendor-specific 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 (11/2009) Section 5.3";
}

typedef interface-type {
  type enumeration {
    enum numbered-interface {
      description "The interface is numbered";
    }
    enum unnumbered-interface {
      description "The interface is unnumbered";
    }
  }
  description
    "Enumeration that defines if an interface is numbered or
    unnumbered";
}
```

```

/*
  Typedef related to references
*/
typedef flexi-grid-link-ref {
  type leafref {
    path
      "/nd:networks/nd:network/lnk:link/lnk:link-id";
  }

  description
    "This type is used by data models that need to reference
    a flexi-grid optical link.";
}

typedef flexi-grid-node-port-ref {
  type leafref {
    path "/nd:networks/nd:network/nd:node/tet:te/"
      +"tet:te-node-attributes/fg-ted:interfaces/"
      +"fg-ted:port-number";
  }
  description
    "This type is used by data models that need to reference
    a flexi-grid port.";
}

typedef flexi-grid-transponder-ref {
  type leafref {
    path "/nd:networks/nd:network/nd:node/tet:te/"
      +"tet:tunnel-termination-point/tet:tunnel-tp-id";
  }
  description
    "This type is used by data models that need to reference
    a trasponder.";
}

/*
  Groupings of attributes
*/
grouping flexi-grid-network-type {
  container flexi-grid-network {
    presence "indicates a flexi-grid optical network";
    description "flexi-grid optical network";
  }
  description "If present, it indicates a flexi-grid
  optical TED network";
}

```

```

grouping flexi-grid-node-attributes {
  description "Set of attributes of an optical node.";

  list interfaces {
    key "name";
    unique "port-number"; // TODO Puerto y TP ID
    description "List of interfaces contained in the node";
    leaf name {
      type string;
      description "Interface name";
    }
    leaf port-number {
      type uint32;
      description "Number of the port used by the interface";
    }

    leaf input-port {
      type boolean;
      description "Determines if the port is an input port";
    }
    leaf output-port {
      type boolean;
      description
        "Determines if the port is an output port";
    }
    leaf description {
      type string;
      description "Description of the interface";
    }
    leaf type {
      type interface-type;
      description "Determines the type of the interface";
    }
    container numbered-interface {
      when "../fg-ted:type =
        'numbered-interface'" {
        description
          "If the interface is a numbered interface";
      }
      description "Container that defines an numbered
        interface with an ip-address";
      leaf n-i-ip-address {
        type inet:ip-address;
        description "IP address of the numbered interface";
      }
    }
  }
}

```

```

    container unnumbered-interface {
      when "../fg-ted:type =
        'unnumbered-interface'" {
        description
          "If the interface is an unnumbered interface";
      }
      description "Container that defines an unnumbered
        interface with an ip-address and a label";
      leaf u-i-ip-address{
        type inet:ip-address;
        description "IP address of the interface";
      }
      leaf label {
        type uint32;
        description "Number as label for the interface";
      }
    }
  }
}

grouping flexi-grid-link-attributes {
  description "Set of attributes of an optical link";
  leaf-list available-label-flexi-grid {
    type bits {
      bit is-available{
        description "Set to 1 when it is available";
      }
    }
  }
  description
    "Array of bits that determines whether a spectral
    slot is available or not.";
}

leaf N-max {
  type int32;
  description "Maximum number of channels available.";
}

leaf base-frequency {
  type decimal64 {
    fraction-digits 5;
  }
  units THz;
  default 193.1;
  description "Default central frequency";
  reference "rfc7698";
}

```

```

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    leaf nominal-central-frequency-granularity {
        type decimal64 {
            fraction-digits 5;
        }
        units GHz;
        default 6.25;
        description
            "It is the spacing between allowed nominal central
            frequencies and it is set to 6.25 GHz";
        reference "rfc7698";
    }

    leaf slot-width-granularity {
        type decimal64 {
            fraction-digits 5;
        }
        units GHz;
        default 12.5;
        description "Minimum space between slot widths";
        reference "rfc7698";
    }
}

grouping flexi-grid-transponder-attributes {
    description "Configuration of an optical transponder";
    //TODO Validate attributes
    leaf-list available-operational-mode {
        type operational-mode;
        description "List of all vendor-specific supported
        mode identifiers";
    }

    leaf operational-mode {
        type operational-mode;
        description "Vendor-specific mode identifier";
    }
}

```



```

    grouping flexi-grid-connectivity-matrix-attributes {
      description "Connectivity matrix between the input and
        output ports";
      list connections {
        key "input-port-id";
        leaf input-port-id {
          type flexi-grid-node-port-ref;
          description "Identifier of the input port";
        }
        leaf output-port-id {
          type flexi-grid-node-port-ref;
          description "Identifier of the output port";
        }
      }
      description "List of connections between input and
        output ports";
    }
  }

/*
   Augments
*/
  augment "/nd:networks/nd:network/nd:network-types" {
    uses flexi-grid-network-type;
    description "Augment network-types including flexi-grid
      topology";
  }
  augment "/nd-s:networks/nd-s:network/nd-s:network-types" {
    uses flexi-grid-network-type;
    description "Augment network-types including flexi-grid
      topology";
  }
  augment "/nd:networks/nd:network/lnk:link/tet:te" +
    "/tet:te-link-attributes" {
    when "/nd:networks/nd:network/nd:network-types/
      fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }
    description "Augment link configuration";
    uses flexi-grid-link-attributes;
  }

  augment "/nd-s:networks/nd-s:network/lnk-s:link/tet-s:te" +
    "/tet-s:te-link-attributes" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
      fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    description "Augment link state";
    uses flexi-grid-link-attributes;
  }
}

```

```

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augment "/nd:networks/nd:network/nd:node/tet:te" +
  "/tet:te-node-attributes" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }
    uses flexi-grid-node-attributes;
    description "Augment node config with flexi-grid attributes";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te" +
  "/tet-s:te-node-attributes" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-node-attributes;
    description "Augment node state with flexi-grid attributes";
  }
augment "/nd:networks/nd:network/nd:node/tet:te"+
  "/tet:te-node-attributes/tet:connectivity-matrices/" +
  "tet:connectivity-matrix" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-connectivity-matrix-attributes;
    description "Augment node connectivity-matrix for node config";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te"+
  "/tet-s:te-node-attributes/tet-s:connectivity-matrices/" +
  "tet-s:connectivity-matrix" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network" {
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-connectivity-matrix-attributes;
    description "Augment node connectivity-matrix for node config";
  }

```

```

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augment "/nd:networks/nd:network/nd:node/tet:te"+
  "/tet:tunnel-termination-point" {
    when "/nd:networks/nd:network/nd:network-types/
fg-ted:flexi-grid-network"{
      description "Augment only for Flexigrid network.";
    }
    uses flexi-grid-transponder-attributes;
    description "Augment node state with transponder attributes";
  }

augment "/nd-s:networks/nd-s:network/nd-s:node/tet-s:te"+
  "/tet-s:tunnel-termination-point" {
    when "/nd-s:networks/nd-s:network/nd-s:network-types/
fg-ted:flexi-grid-network"{
      description "Augment only for Flexigrid network.";
    }

    uses flexi-grid-transponder-attributes;
    description "Augment node state with transponder attributes";
  }
}

<CODE ENDS>

```

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## 7. Security Considerations

The transport protocol used for sending the managed information MUST support authentication and SHOULD support encryption.

The defined data-model by itself does not create any security implications.

## 8. IANA Considerations

The namespace used in the defined models is currently based on the METRO-HAUL project URI. Future versions of this document could register a URI in the IETF XML registry [RFC3688], as well as in the YANG Module Names registry [RFC6020].

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## 10. Contributors

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ISIS Extensions for Flexible Ethernet  
draft-zcdc-isis-flexe-extention-01

Abstract

This document specifies the extensions to the IS-IS routing protocol to carry and flood Flex Ethernet (FlexE) link state information. The FlexE link state information is necessary for a node or a controller to compute a path that is required to over FlexE links.

Requirements Language

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

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## 1. Introduction

Flex Ethernet (FlexE) [I-D.izh-ccamp-flex-e-fwk] provides a generic mechanism for supporting a variety of Ethernet MAC rates that may or may not correspond to any existing Ethernet PHY rate. This includes MAC rates that are both greater than (through bonding) and less than (through sub-rate and channelization) the Ethernet PHY rates used to carry Ethernet traffic.

FlexE supports interface bonding, a bonded interface is consisted of from 1 to n 100GBASE-R PHYs (other types of PHY will be supported in the future), the bonded interface is called FlexE interface in this document. FlexE also supports interface channelization, a FlexE interface can be channelized into multiple sub-interfaces, the sub-interface is called FlexE sub-interface in the rest of this document.

The FlexE mechanism operates using a calendar which assigns 66B block positions on sub-calendars on each PHY of a FlexE interface to each of the FlexE flows. The calendar has a granularity of 5G, and has a length of 20 slots for a 100G interface. Currently, only 100GBASE-R PHY and 5G granularity are supported in FlexE implementation

agreement version 1.0 [FlexE], other types (e.g., 200G, 400G) of PHY and granularities (e.g., 25G) will be supported in the future.

A FlexE interface has a number of time slots resource. These time slots can be transparent to the up layer application, the up layer application (e.g., RSVP-TE) can just treat the FlexE interface as a normal Ethernet interface, or the time slots can be allocated to a FlexE LSP through RSVP-TE signaling, or the time slots can be allocated to form a FlexE sub-interface through configuration or some dynamic protocols. How to signal the FlexE LSP or configure the FlexE sub-interface is out of the scope of this document.

The logical link that connects two FlexE interfaces residing in two adjacent nodes is called FlexE link, and the logical link that connects two FlexE sub-interfaces residing in two adjacent nodes is called FlexE sub-link.

More details about FlexE can be found in FlexE framework document [I-D.izh-ccamp-flexe-fwk].

This document defines extensions to ISIS protocol to advertise the FlexE TE link and sub-link state information.

## 2. FlexE Link Advertisement

This document re-uses the Interface Switching Capability Descriptor (ISCD) sub-TLV for the advertisement of FlexE link state information. The ISCD is a sub-TLV of the extended IS reachability TLV [RFC5307], it is defined to describe the switching capability of an interface. The following figure (Figure 1) illustrates encoding of the Value field of the ISCD sub-TLV.

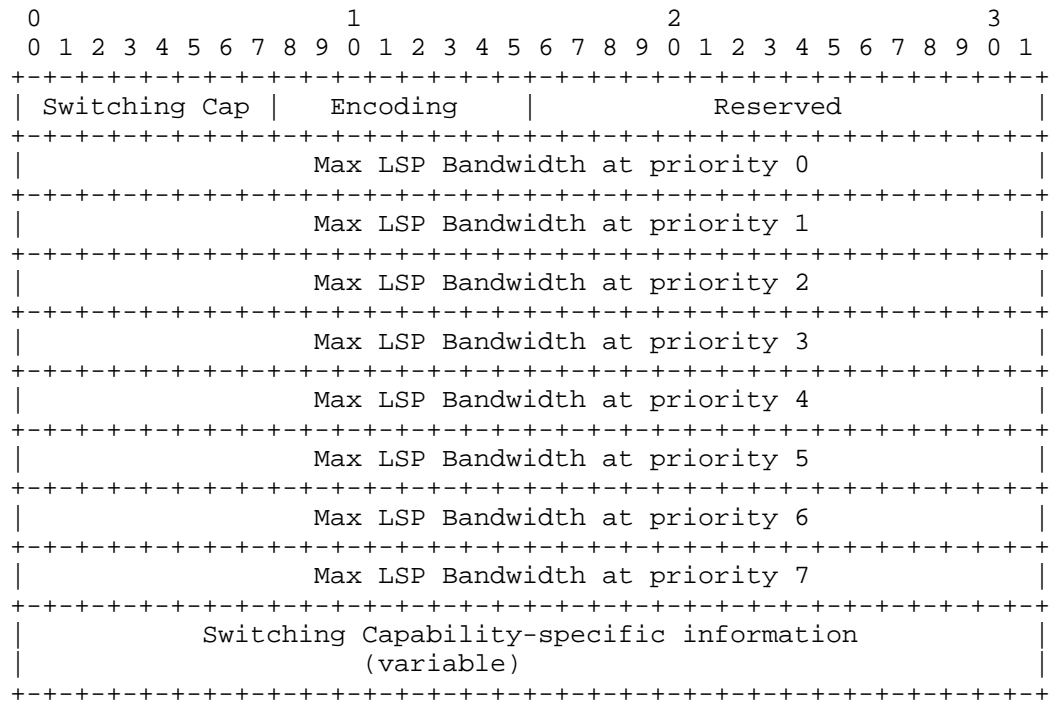


Figure 1: ISCD sub-TLV

To support FlexE link advertisement, new "Switching Cap" and "Encoding" are defined as follows:

The Switching Capability (Switching Cap) for FlexE interface is as below:

Value	Name
TBD1	FlexE-Switching

The Encoding Type for FlexE:

Value	Name
TBD2	FlexE

The "Switching Capability-specific information" field for FlexE interface is defined as below. It is referred to as FlexE Interface sub-TLV in this document.

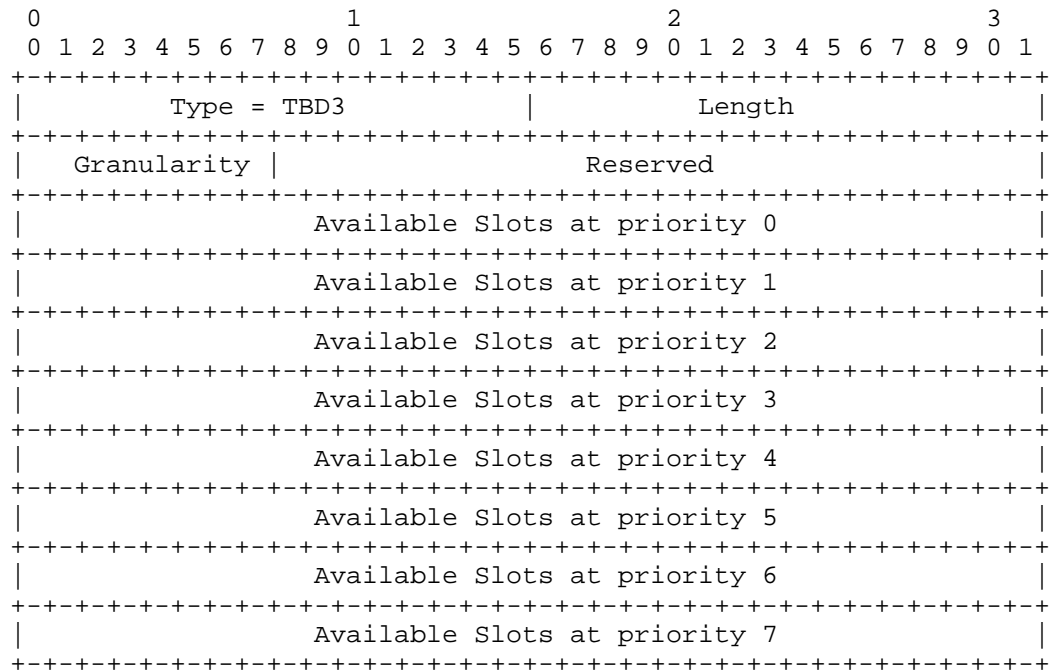


Figure 2: FlexE Interface sub-TLV

The Type field is 2 octets in length and the value is TBD3.

The Length field is 2 octets in length that indicates the total length of the TLV in octet.

The Granularity is 1 octet in length and its value identifies the granularity of the FlexE time slots of a FlexE interface. Current OIF agreement only allows the "5G" granularity, other granularities may be defined in the future.

Value	Granularity
-----	-----
0	Reserved
1	5G
2-254	Unassigned
255	Reserved

For each PHY of a FlexE interface, there are two calendars, one is called Active calendar and the other is called Backup calendar. The two calendars are used to facilitate reconfiguration, for example,

FlexE flow resizing can be achieved through calendar updates. More detail about FlexE calendar can be found [FlexE].

Each Available Slots at priority n is 4-octet in length that indicates the maximum number of slots available at priority 'n' on active calendar of the FlexE interface.

For a FlexE interface, as said above, 5G granularity is only supported for now, but multiple granularities may be supported in the future. To support this, FlexE Interface sub-TLV can occur multiple times in a ISCD sub-TLV, but for each granularity, only one FlexE Interface sub-TLV can be included and it carries the available time slots of the granularity of the FlexE interface. When multiple FlexE Interface sub-TLVs for the same granularity occur, only the first FlexE Interface sub-TLV is considered to be valid, the rests MUST be ignored.

### 3. FlexE Sub-link Advertisement

Through FlexE channelization, a FlexE Link can be sliced into a number of FlexE sub-links, each FlexE sub-link has dedicated bandwidth and is isolated from other FlexE sub-links. A set of FlexE sub-links can be allocated to a specific application/user to form a sliced network. From link characteristic point of view, a FlexE sub-link is same as a real point-2-point link, it can be advertised and used as a normal point-2-point link.

## 4. IANA Considerations

### 4.1. FlexE Switching Type

IANA is requested to allocate a new switching type from the "Switching Types" registry of "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry.

Value	Name	Reference
-----	-----	-----
TBD1	FlexE-Switching	This document

### 4.2. FlexE LSP Encoding Type

IANA is requested to allocate a new LSP encoding type from the "LSP Encoding Types" registry of "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry.

Value	Name	Reference
-----	-----	-----
TBD2	FlexE	This document

#### 4.3. FlexE Interface Sub-TLV

IANA is requested to create and maintain a new sub-registry, the "Types for sub-TLVs of FlexE Switching Capability Specific Information" registry under the "IS-IS TLV Codepoints" registry.

Value	sub-TLV Name	Reference
-----	-----	-----
TBD3	FlexE Interface	This document

#### 5. Security Consideration

This document describes a mechanism for advertising FlexE link state information through IS-IS LSPs and does not introduce any new security issues.

#### 6. Acknowledgements

#### 7. References

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