Open ROADM Network Model, Version 13.1.0

Open ROADM MSA

2024/04/05

Network Model Whitepaper

Provides documentation for YANG network models defined for Open ROADM MSA.

Document Revision History

Date	Revision	Description
July 14, 2016	1.0	Initial issuance
July 21, 2016	1.1	Document updated to address comments
March 30, 2018	2.2	Updated to reflect v2.2 Open ROADM data models
December 7, 2020	7.1.0	Document updated to have 7.1.0 model support
April, 2024	13.1.0	Document updated to have 13.1.0 model support

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The data collected in the Inventory Database in the Open ROADM Control Layer depends on how the equipment's information models are defined.

- The information model at the network level should be vendor-agnostic. It is used by the Open ROADM Control Layer to identify resources that are needed for creating services and the relationships of the network resources to each other.
- The information model at the device level is vendor specific. Inventory data collected based on the device model is specific to vendors' equipment and configurations.

1 Open ROADM Network Information Model

The Network model from release 4.x onwards is based on RFC-8345 [1] and uses ietf-network@2018-02-26.yang and ietf-network-topology@2018-02-26.yang as base models. The Open ROADM Network model provides augmentations to these models. The augmentations contain attributes specific to the network elements and links of DWDM and OTN layer.

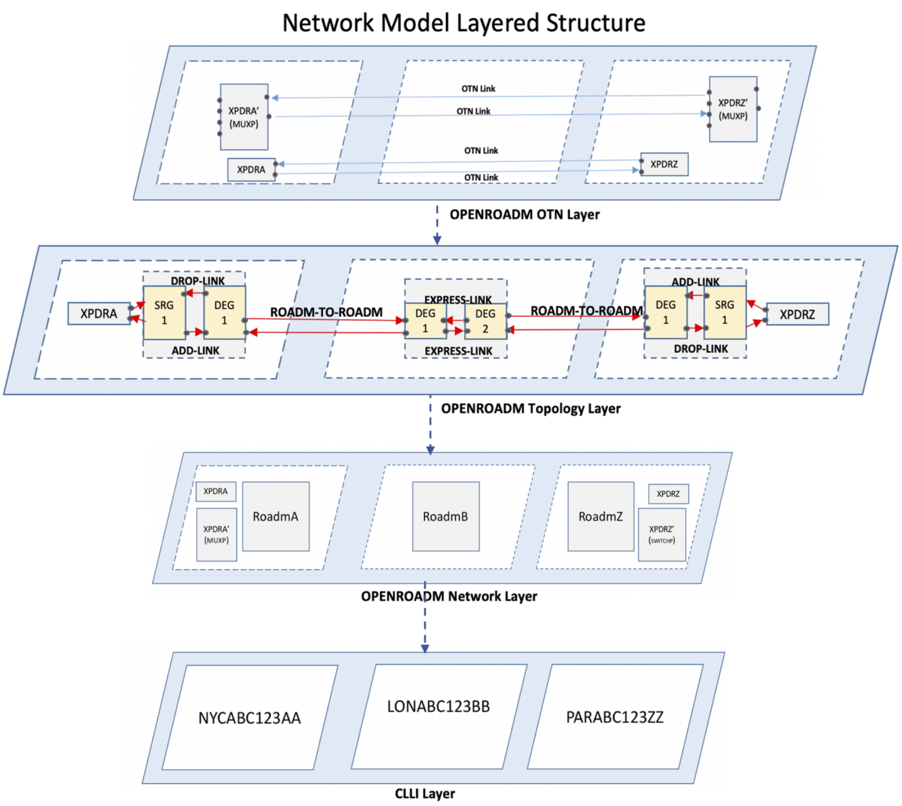


Figure 1: Three layered architecture for DWDM network.

1.1 Network Model I2RS Enhancements

The DWDM network is divided into 3 layers to simplify network monitoring and management. The OTN network is modeled as an additional layer that builds on top of the DWDM OPENROADM topology layer. Each layer is uniquely identified in the network based on the attribute "network-id" and has its own set of nodes and optionally termination points and links. A node in a layer is uniquely identified with the attribute "node-id" and within the entire network based on combination of the network-id and node-id. A link in a layer is uniquely identified based on the "link-id" attribute and within the entire network using combination of network-id and link-id. The attributes "network-ref", "node-ref" and "link-ref" hold the network-id, node-id and link-id of their respective parents (supporting-nodes).

The naming convention for "network-id" is as follows:

- **clli-network**

  The clli-network layer holds the list of all the office locations where the Open ROADM equipment (ROADM, transponder, Muxponder etc.) can be planned or deployed. Nodes in the layer are office locations. Termination points for this layer can be ROADMs, transponders or other OpenROADM equipment located in the office. Links and termination points may be optionally added into CLLI layer. The value of CLLI (office) in this layer is based on preference of the service provider.

- **openroadm-network** This layer holds equipment management level information such as vendor, IP, plan due date, maintenance schedule, shelf, model, software version etc. The "network-ref" for this layer is openroadm-network . The network-ref of its supporting network (or parent) is clli-network and all the nodes within same CLLI (office) will point to the same CLLI node in the clli-network. The openroadm-network layer is an underlay to the clli layer. This layer can have termination points and links depending on service provider's preference. It inventories all the OpenROADM equipment planned or deployed in the network. Openroadm-network layer can have following node types:

  1. ROADM
  2. XPONDER
  3. EXT-PLUGGABLE

- **openroadm-topology**

  The openroadm-topology layer holds the disaggregated view (degree and SRG for ROADM, multiple transponder card within an xponder) of the OpenROADM equipment. Information in this layer can be used by applications such as PCE (path computation engine), provisioning, power control etc. Each node in this layer is expected to have a number of "termination-points" that map directly to the attribute "logical-connection- point" in the device model. Spectrum availability or usage for each termination point should be reflected using avail-freq-mapsused-wavelengths. Spectrum usage should be updated after every service turn-up/turn-down to reflect the available spectrum. Openroadm-topology layer can have following node types:

  1. DEGREE A degree node will have following termination point types if ports are bi-directional:
     (a) DEGREE-TXRX-TTP
     (b) DEGREE-TXRX-CTP

     And the following if ports are unidirectional:
     (a) DEGREE-TX-TTP
     (b) DEGREE-RX-TTP
     (c) DEGREE-TX-CTP
     (d) DEGREE-RX-CTP
  2. SRG A SRG node will have following termination point types if ports are bi-directional:
     (a) SRG-TXRX-CP
     (b) SRG-TXRX-PPn (count based on device)

     And the following if ports are unidirectional:
     (a) SRG-TX-CP
     (b) SRG-TX-PPn (count based on device model)
     (c) SRG-RX-CP
     (d) SRG-RX-PPn (count based on device model)
  3. TPDR or MUXPDR or SWITCH A transponderMuxponder or OTN switch, based on the device manufacturer can have following set of termination point types:
     (a) XPONDER-NETWORK (count based on device model)
     (b) XPONDER-CLIENT (count based on device model)
  4. REGEN or REGEN-UNI

     A bidirectional or unidirectional REGEN node can have following termination points types:
     (a) XPONDER-NETWORK (count based on device model)

(b) XPONDER-CLIENT (count based on device model)

With release 2.x the devices model supports flexible grid capability for DWDM systems. In release 1.x, the fixed grid model was supported. Under the fixed grid OpenROADM systems, the wavelengths were uniquely identified with an attribute “wavelength-number” that ranged from 1 to 96 and each number had a predefined center frequency and wavelength. The mapping from wavelength number to center frequency and width was found in the file “org-openroadm-wavelength-map.txt”. However, in release 2.x the fixed grid model is replaced with the flex grid model. In flex grid systems, the mapping is no longer fixed. In order to support this capability in the network model each wavelength is referred based on arbitrary index that holds the frequency and width information for the signal (at nodes Degree, SRG, XPONDER etc.). The “index” attribute is used to store the grid less wavelengths within a node and may or may not be unique in the network based on controller implementation. Starting from network model release 5.0, available frequency maps are added into openroadm-topology layer, which represents 96 bytes of binary information and can describe the spectrum occupation (at Degree and SRG nodes). Frequency is the center frequency for the wave and is expressed in THz and width is expressed in GHz. The Openroadm-topology layer also holds the information related to links external to a node, which can be of the following types:

1. EXPRESS-LINK
2. ADD-LINK
3. DROP-LINK
4. ROADM-TO-ROADM
5. XPONDER-INPUT
6. XPONDER-OUTPUT
7. REGEN-INPUT
8. REGEN-OUTPUT
9. TURNBACK-LINK

Since all the disaggregated elements within a ROADM may not be fully connected (e.g. Degree N not connected to Degree N+1) the data for express, add and drop link can be derived from the physical or internal links or connection-map in the device model or a planning application that is aware of such restrictions. The data for ROADM-TO-ROADM links can be discovered by the controller based on the Link Layer Discovery Protocol (LLDP) information reported under the “protocols” subtree in the device model and validated against the planned state.

- **otn-topology** The OTN network is modeled using OTN topology layer. It holds network information for OTN elements including Muxponders, OTN switches/switchponders, Transponders and Regens. OTN topology layer is built on top of openroadm-topology. This layer is consisting of nodes, termination points and links The nodes in this layer are as follows:

  1. SWITCH
  2. MUXPDR
  3. TPDR
  4. REGEN
  5. REGEN-UNI

  Since OpenROADM MSA release 3.0.0, a new layer has been added to the Network models. This layer is named ‘openroadm-common-network’. It does not modify the existing layers hierarchy of the Network model and will not show up in the logically abstracted view shown in Figure 1. Openroadm-common-network layers is added to simplify the manageability of the yang code. The common parameters that were earlier defined multiple times in different files are now put in the single file org-openroadm-common-network.yang and it augments into I2RS node, termination point and link directly. The attributes that have been moved into openroadm-common-network are defined in Table 1, Table 2 and Table 3.

Attribute	Description	Note
node-type	Specification of the type of the node, ROADM, DEGREE, SRG, XPONDER, EXT-PLUGGABLE, TPDR, MUXPDR, REGEN, REGEN-UNI, SWITCH . . .	Data from planning
lifecycle-state	Life cycle state of a node (planned, deployed or maintenance)	
operational-state	Operational state of the node	Set by SDN controller
administrative-state	Administrative state of the node	Set by SDN controller

Table 1: Augments associated to I2RS node.

Attribute	Description	Note
tp-type	Type of termination point e.g TTP, CTP, . . . physical-tp True when the termination point maps to ports of an existing circuit-pack, False, when mapped to a slot (pluggable optics Holder) $\rightarrow$ virtual tp	Applies to Termination Points that map to physical ports or slots on circuit packs. This attribute is not present for other Termination Points.
associated-connection-map-tp	Used to identify relationships between client and network ports in transponders and unidirectional regens. Provides the list of tps the tp is connected to, as defined in the device connection map.	
eqpt-srg-id	Shared Risk Group identifier for the termination point.	All ports in a circuit-pack will have same srg-id
lifecycle-state	Life cycle state of a termination point (planned, deployed or maintenance)	Set by SDN controller
operational-state	Operational state of the tp	Set by SDN controller
administrative-state	Administrative state of the tp	Set by SDN controller

Table 2: Augments associated to I2RS Termination Point.

Attribute	Description	Note
link-type	Link type e.g. EXPRESS-LINK, ADD-LINK, DROP-LINK, OTN-LINK etc.	Add, Drop and Express links can be auto detected based on connection map from the device. ROADM-TO-ROADM can be detected using LLDP subtree from the device model. Xponder-input, Xponder-output Links data from planning. OTN-link created by controller if an OTN service exists between endpoints
clfi	Unique identifier of the link	Data from planning
opposite-link	Identifier of the link carrying traffic in opposite direction	
link-length	Link-length in kilometers	Data from planning
link-latency	Latency of link milliseconds	Data from planning
TE-metric	Traffic engineering metric which could be used for any type of link	
Link-concatenation		Data for planning
SRLG-ID	Unique identifier for SRLG	
SRLG-length	Fiber length in meters	
administrative-group?	Defined in RFC 3630 section 2.5.9. Corresponds to the value of one or more administrative groups the links belongs to.	Data from planning
operational-state	Operational state of the link	Set by SDN controller
lifecycle-state	Life cycle state of a termination point (planned, deployed or maintenance)	Set by SDN controller

Table 3: Augments associated to I2RS link.

1.2 CLLI-network layer

The clli-network layer holds the list of all the office locations where the OpenROADM equipment (ROADM, transponder etc.) can be planned or deployed. Nodes in the layer are office locations. The value of node-id/clli, termination points and links in this layer can be based on preference of the service provider. A node attributes for this layer are listed in Table 4.

Attribute	Description	Note
clli node-id	Location CLLI where ROADM resides	Data from planning
	Network-wide unique identifier for an openroadm node (ietf-network attribute)	office CLLI

Table 4: Augments associated to I2RS link.

1.3 Openroadm-network Layer

This layer holds equipment management level information such as vendor, IP, plan due date, maintenance schedule, shelf, model, software version. The "network-ref" of the parent/supporting layer is clli-network and all the nodes within same CLLI (office) will point to the same CLLI node in the clli-network. The openroadm-network layer is an underlay to the CLLI layer. It inventories all the OpenROADM equipment planned or deployed in the network.

Nodes in this layer are as follows:

1. ROADM
2. XPONDER

3. EXT-PLUGGABLE

Node attributes for openroadm-network layer are listed below in Table 5:

Attribute	Description	Note
node-id	Network-wide unique identifier for an openroadm node	Constructed by concatenating office identifier, bay identifier, shelf identifier
supporting-node • network-ref • node-ref	Reference to supporting network and node with in supporting network layer	Set by SDN controller
software-version	Vendor software version	Data obtained from device
openroadm-version	OpenROADM yang model release version	Data obtained from device
vendor	Identifier of the supplier for the openroadm equipment	Data from planning, if life-cycle state is planned
model	Identifier of the supplier's equipment	Data from planning, if life-cycle state is planned
domain-subnetwork	Specific Domain-Subnetwork in which the openroadm devices reside	Data from planning, if life-cycle state is planned
ip	IP address assigned to the openroadm node	Data from equipment engineering, if life cycle state is planned
relay-rack	Frame Identification Code (FIC)	Data from equipment engineering, if life cycle state is planned
shelf	Shelf in which the NE controller is equipped	Data from equipment engineering, if life cycle state is planned
node-connection-status	Status of connection between Device and Controller. Possible values are: CONNECTED, CONNECTING, UNABLE-TO-CONNECT	Set by SDN controller

node-capabilities • *supported-xpdr-list* – *supported-xpdr* [xpdr-type]* ⋆ *xpdr-type* ⋆ *recolor* ⋆ *supported-operational-modes* [operational-mode-id]* · *operational-mode-id* · *equipment-capacity* · *equipment-available*	Node capabilities data allows supported operational-mode(s) to be defined per xponder node. Equipment-capacity indicates the ability to add a shelf, circuit-pack, etc. Equipment-available indicates that planned or deployed equipment is available in the node. Granularity is determined by the carrier based on their operation (e.g. circuit-pack must be available, plugguable must be available). May be determined by carrier OSS rather than controller depending on how service assignments are made. *recolor* boolean is used to indicate if node is capable of recoloring	*supported-xpdr** and *supported-operational-modes* [operational-mode-id]* are leaf-list
roadm-attributes • *max-degrees* • *max-srgs* • *current-degrees* • *current-srgs*	ROADM information like max and current number of degrees and SRGs.	Data obtained from device
xpdr-attributes • *customer-code*	Xponder attributes like customer code.	Data obtained from device
pluggable-attributes • *pluggable-id* • *customer-code* • *tail* – *client-equipment* – *client-equipment-id* – *clfi*	Pluggable attributes like customer code and tail.	Data obtained from device

plan-due-dates • *due-dates* – *id* – *start-date* – *end-date*	Start and End dates for planned node	Data from planning
node-maintenance-schedule • due-dates – id – start-date – end-date	Maintenance schedule for the node	Data from planning

Table 5: Attributes associated to a OpenROADM Network Layer node.

1.4 Openroadm-topology Layer

The openroadm-topology layer holds the disaggregated view (degree and SRG for ROADM, multiple transponder card within an xponder) of the OpenROADM equipment. Every ROADM is composed of a number of directionsdegrees and a number of adddrop groups, as illustrated in Figure 2. Thus, “directiondegree” and “adddrop group” are the two basic building blocks for a ROADM. In document we use adddrop group and SRG in the same context.

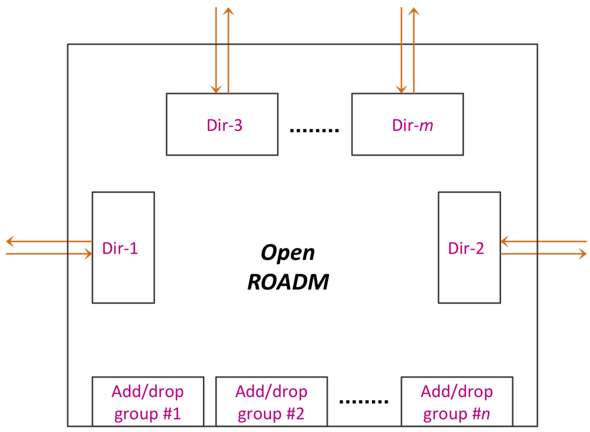


Figure 2: A generic representation of an m-degree ROADM with n add/drop groups (SRGs).

For colorless/directionless (CD) ROADM or colorless/directionless/contentionless (CDC) ROADM, the directionsdegrees and adddrop groups can be planned and deployed separately and independently.

1.4.1 Direction/Degree

At the network level, a degree of ROADM can be plainly made to have just external connections that are connected to another ROADM in an adjacent office and internal connections to support express and adddrop traffic. Thus, a directiondegree building block (or construct) can be represented by a pair of TTP’s (trail termination points) and a pair of CTP’s (connection termination points), as shown in Figure 3.

The two TTP’s correspond to the incoming port of the pre-amp amplifier and the outgoing port of the booster amplifier in a directiondegree. The two physical ports supporting the TTPs are connected to another directiondegree of another ROADM in a neighboring office via outside plant (OSP) fiber. Inter-office OSP fiber is terminated on high-speed (HS) LGX in central offices. Thus, the two unidirectional links between the directions/degrees of two connected ROADM nodes are through HS LXs and OSP fiber, as shown in Figure 4.

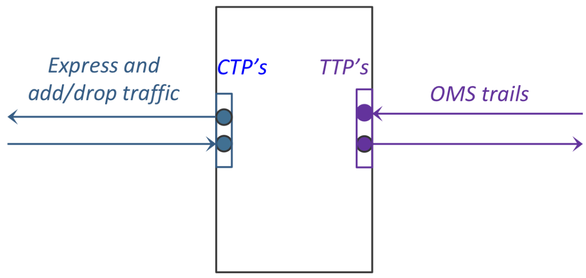


Figure 3: Network representation of a ROADM degree.

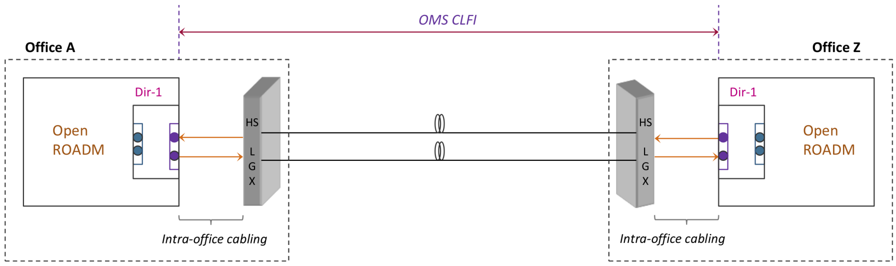


Figure 4: Connections between two ROADM nodes.

The HS LGX jack #s through which the ROADM's optical amplifiers are connected to outside plant fiber are identified manually through planning and equipment engineering process. The information can be transparent to the Network Model, but the information needs to be tracked in the Inventory Database in the Open ROADM Controller, i.e., the intra-office cabling shown in Figure 4 must be explicitly inventoried. LGX data is not yet part of OpenROADM models.

The two CTP's correspond to multiple physical ports in the ROADM device where signals of express channels from other directionsdegrees and signals of add/drop channels from different adddrop groups are received and transmitted. At the network level, those physical ports are combined into a transmit (Tx) CTP and a receive (Rx) CTP. The attributes associated to each degree of a ROADM are specified in Table 6:

Attribute	**Description**	**Note**
degree-number	Identifier for each direction/degree	Data from planning
max-wavelengths (N)	Max number of wavelengths supported by a degree in fixed grid model	Data obtained from device
ingress-span-loss-aging-margin	Span-loss margin extracted from corresponding device OTS interface container, optional	Data obtained from device
eol-max-load-pIn	End Of Life Total input power at maximum load extracted from corresponding device OTS interface container	Derived from device
egress-average-channel-power	Total max power across the 4.8 THz passband	Set by SDN controller

avail-freq-maps • *map-name* • *start-edge-freq* • *freq-map-granularity* • *effective-bits* • *freq-map*	The spectrum occupation is defined by a list of available frequency maps. One map corresponds to one band (Open-ROADM specifications only address C-Band at that time, so that only one map will be populated). For each map we define the start frequency, the map granularity which is derived from the device (it depends on the WSS technology and is provided in the device mc-capabilities), the number of effective bits used in the binary to cover all the spectrum (one bit corresponds to one elementary slot of the spectrum), and the freq-map, a binary, for which the number of bits is defined by "effective-bits". An available elementary slot will correspond to a 1. A used slot will correspond to a 0.	Derived from the device and updated by SDN controller (freq-map)
type-variety	Equipment type variety defined by the Open ROADM MSA or by the vendor for bookending applications	

Table 6: Attributes associated to a ROADM degree.

The TTP's and CTP's are logical ports. They are created to assist modeling of signal flow between devices. If each degree can support maximum of 96 wavelengths (i.e., the N in Table 6 equals to 96) in case of fixed grid, the TTP's are then modeled with 96 termination points in the transmit (Tx) direction and 96 termination points in the receive (Rx) direction. Similarly, the CTP's are modeled with 96 connection points in the transmit (Tx) direction and 96 connection points in the receive (Rx) direction. In the flex-grid model, the number of supported channels may vary according to their spectral-width. The CTP's are points associated to a specific degree where traffic inside a ROADM is aggregated from other degrees and from local add/drop groups of the ROADM. The TTP's are also points associated to a specific degree, however the traffic at those point is going to and coming from another ROADM that is connected through outside plant fiber.

Figure 5 illustrates the multi-wavelength TTP's and CTP's in fixed grid model, where the incoming OMS trail is terminated at OMS-TTP-Rx. Using maximum of 96 wavelengths as the example, 96 termination points are fanned out from OMS-TTP-Rx; each one can be assigned to a wavelength-level service. Similarly, 96 termination points are fanned out for the OMS-TTP-Tx in Figure 5 so that 96 wavelengths can be used for services to ride on the OMS trail to the other ROADM node. The CTP's are modeled the same way as TTP's. 96 wavelengths can be the input to the CTP-Rx in Figure 5, and, in the opposite direction, 96 wavelengths can be the output from the CTP-Tx.

A servicecircuit coming in one of a ROADM degree is received at its external OMS-TTP-Rx with a specific wavelength. The connection point of the same wavelength in the internal CTP is used to direct the signal to other part of the ROADM, e.g., in Figure 6, λ_4 in CTP-Tx is matched to λ_4 in OMS-TTP-Rx. In the reverse direction, the same service received at CTP-Rx will be transmitted out to another ROADM via OMS-TTP-Tx. Therefore, the 96 connection termination points in CTP-Tx are one-to-one connected to the 96 trail termination points in OMS-TTP-Rx. The 96 connection termination points in CTP-Rx are one-to-one connected to the 96 trail termination points in OMS-TTP-Tx.

Since the OMS trails are terminated on the TTPs, tracking services that are routed on a particular OMS trail can be accomplished through the TTP associated to the OMS trail. Starting release 5.0 available frequency maps are added as degree attribute to capture available spectrum information for ROADMs supporting flexible grid capability. Available frequency map has information regarding, starting edge frequency of the spectrum, frequency map granularity supported by the roadm, frequency map and number of effective bits in frequency map. Bits in the frequency map is decided by slot width granularity supported by ROADM. For example, if a

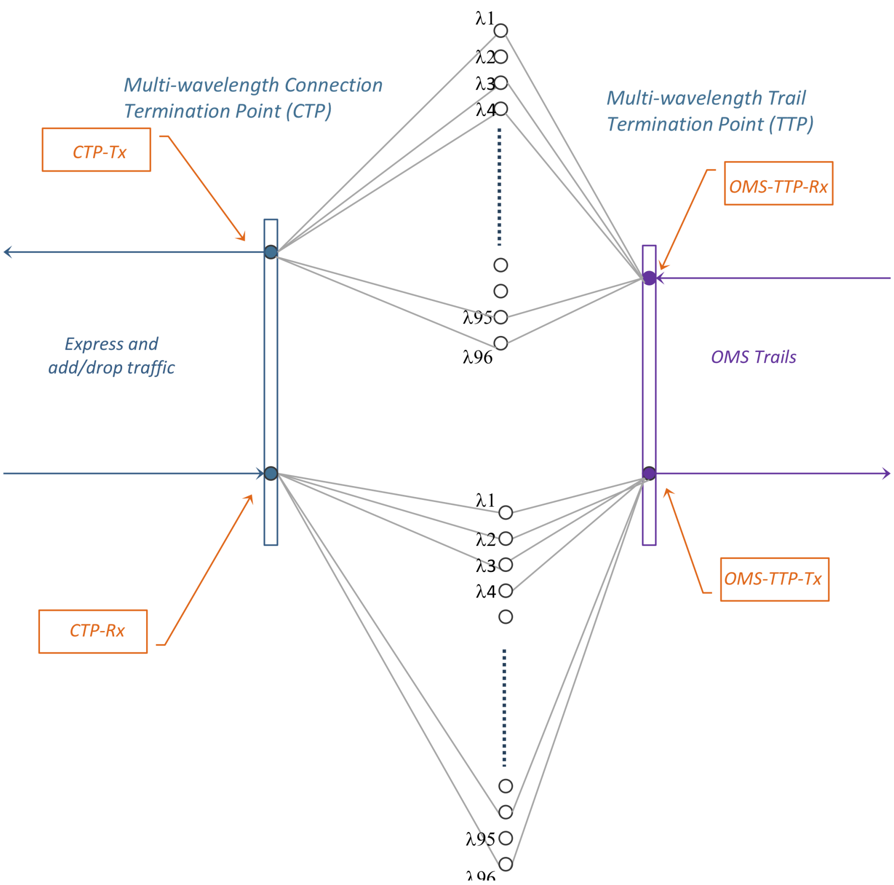


Figure 5: Multi-wavelength TTP and CTP in the Direction/Degree construct.

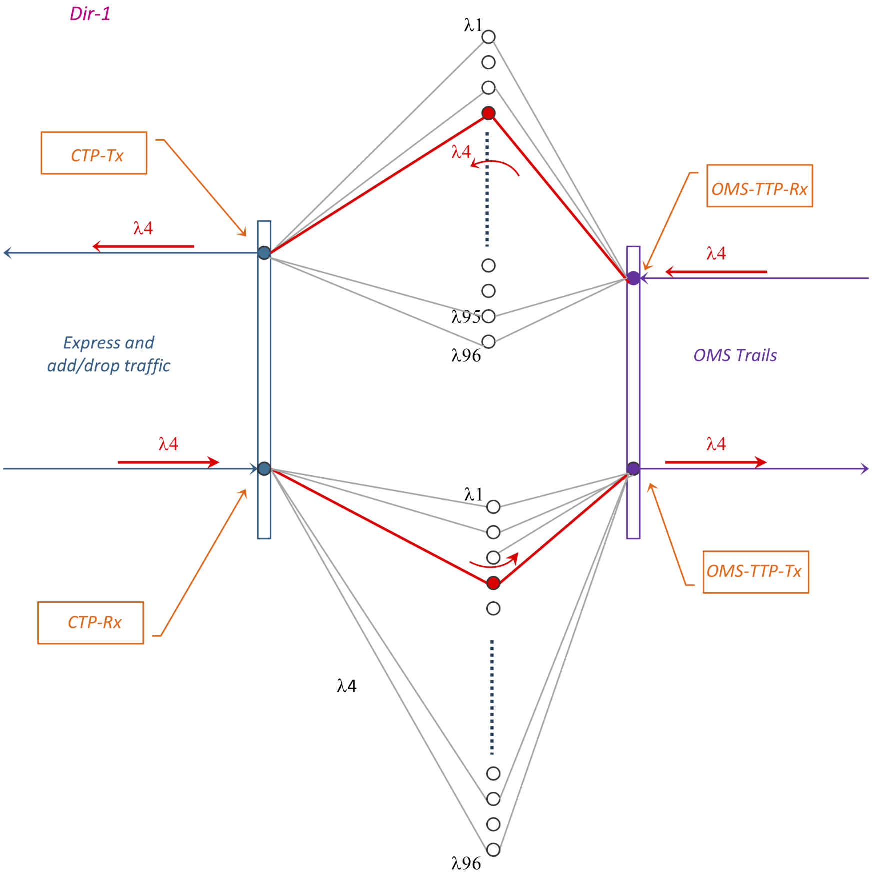


Figure 6: Wavelength #4 (λ_4) is assigned to a service supported by Dir-1 of a ROADM.

flex-gird ROADM has 6.25 GHz of slot width granularity and 191.325-196.125 THz of spectrum range then spectrum availability can be captured using 768 bits. Setting the value of the binary bit to 1 indicates that the corresponding spectrum is available and setting to 0 indicates the corresponding spectrum is unavailable. For more information on frequency map please refer to RFC-8363[2].

1.4.2 Add/Drop Group/SRG

Each adddrop group (SRG) is equipped with a number of port pairs to support local adddrop traffic. Within each port pair (pp), there is one transmit (Tx) or OUT port and one receive (Rx) or IN port. Those TxRx port pairs in an adddrop group may be supported by the same group of circuit packs or by different groups of circuit packs. The equipment in a group shares the same risk and is considered a Shared Risk Group (SRG). Thus, the three adddrop groups shown in Figure 7 are considered to be three separate SRG's.

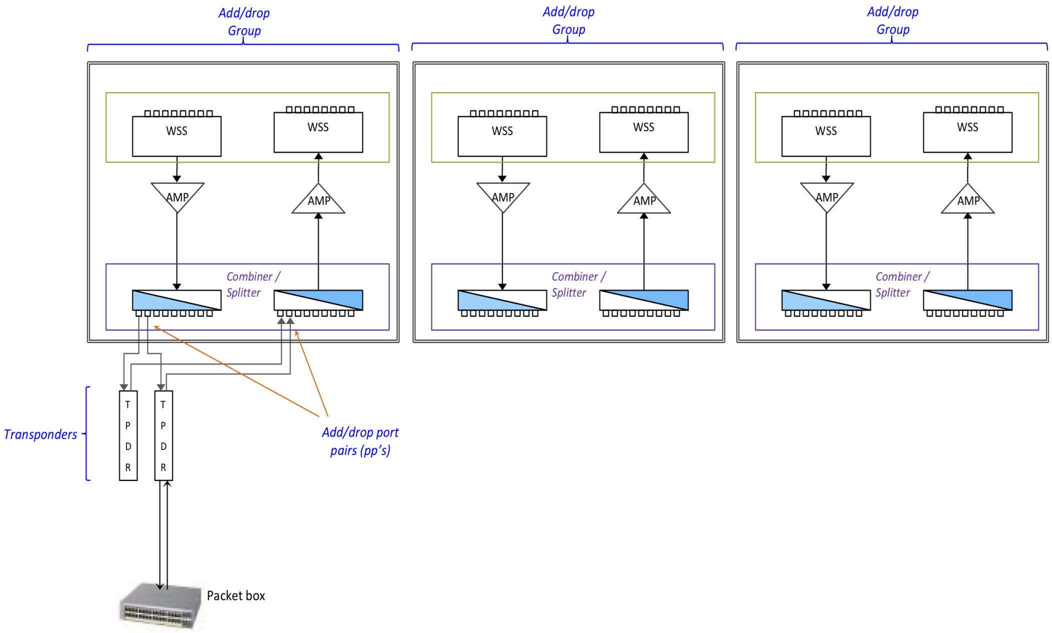


Figure 7: Three adddrop groups correspond to three SRGs.

The number of SRG's in an add/drop group varies depending on vendor's equipment configuration. Since the Open ROADM Controller needs the information to assign wavelength numbers for new services and select equipment SRGs to assign new services for add/drop, an add/drop group construct can be modeled at the network level to consist of a vendor specific number of SRGs, where each SRG is made up of

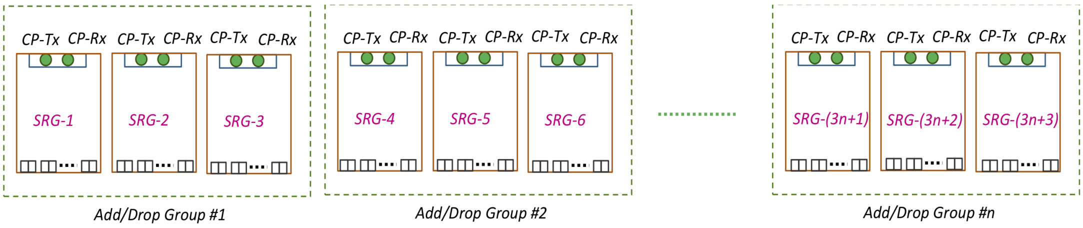
- A pair of CP's (Connection Points), one Tx CP and one Rx CP
- A vendor specific number of add/drop port pairs (pp's)

The adddrop port pairs are connected to transpondersmuxponders to transport local traffic. The traffic is then directed to ROADM directionsdegrees via the CP's.

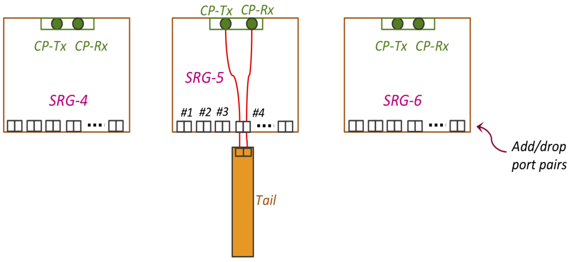
Figure 8a depicts n adddrop groups with three SRGs within each adddrop group[1]. A pair of CP's (Connection Points) is included each SRG. Applying the model to the adddrop group example shown in Figure 7, the configuration is simplified with three pairs of CP's and a "tail", as shown in Figure 8b. The "tail" contains the packet box equipment and transponder that are pre-cabled together with the transponder being connected to an adddrop port pair (#4) in the 2nd SRG (Figure 8).

The number of port pairs in an adddrop group or in an SRG is vendor specific. All those ports are used for intra-office connections between the ROADM and client equipment. The connections, also known as "tails", may be direct interfaces with client equipment or may go through transponders or muxponders and intermediate LGXs (refer to Section 1.6 for tail equipment configurations). SRGs are critical to the ROADM Controller to perform network functions, e.g., assigning services to equipment taking diversity routing constraint into consideration, due to the following:

[1]The OpenROADM v2.x models only support a 1:1 relationship between an add-drop group and SRGs.



(a) A pair of Connection Points (CPs) is assigned to each SRG in an Adddrop group construct that contains three SRGs.



(b) A “tail” facility is created via the 2nd SRG in a 3-SRG adddrop group.

Figure 8: Interconnection of tail, SRG and CPs

- A CD add/drop group will fail to function if there is an equipment problem in the group; hence the whole add/drop group is considered as one SRG.
- A CDC add/drop group is comprised of multiple SRGs. Equipment failure in one of the SRGs will bring down only one SRG; the other SRGs in the same add/drop group remain functional.

Thus, adddrop group construct is not required for the Network Model. Adddrop groups can be used for equipment planning and ordering but add/drop groups need to be converted to SRGs and included in the Network Model, e.g., the add/drop group numbers, i.e., $1, 2, \ldots, n$, in Figure 8a can be transparent to the Network Model but the SRG numbers i.e., $1, 2, 3, 4, 5, 6, \ldots, 3n + 1, 3n + 2, 3n + 3$, in Figure 8b must be included in the Network Model.

Traffic routed through the CP's require wavelength assignment. The PCE in the ROADM Controller assigns wavelengths to services when services are first created. The CP's of CDC SRG support wavelength duplication, whereas the CP's of CD SRG do not. This distinction is illustrated in Figure 9a and Figure 9b (Figure 9).

The information associated to each SRG of a ROADM contains the attributes specified in Table 7

Note: The number of port pairs (pp's) in an SRG can be determined by one of the following approaches:

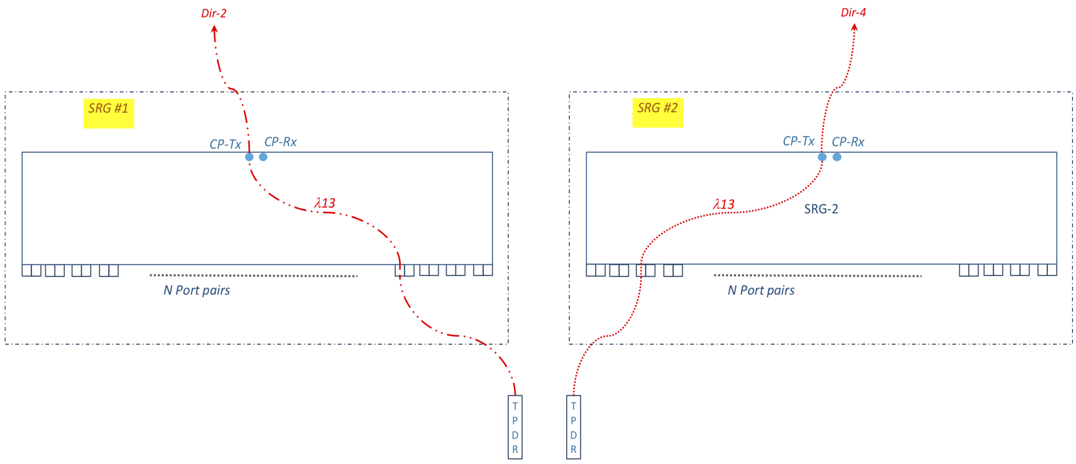
- Discovered from the network, i.e., via an API (e.g., getAllEquipment) that is provided by vendor's Device Model [4].
- Provided by vendor's static meta-data as part of their Device Model that says “for an SRG of hardware pack type X, Npp ports”.

1.4.3 Logical Connectivity Links

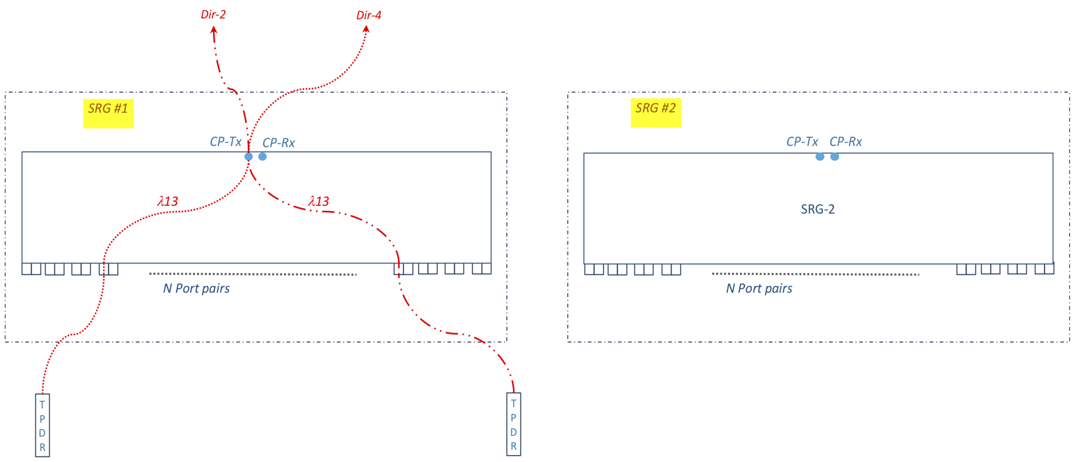
Connectivity between degrees and between degrees and SRGs within a ROADM is represented by logical links that connect the logical points in ROADM degrees, i.e., TTPs and CTPs, and the logical points in SRGs, i.e., CPs. The naming convention of the logical connectivity links is as follows:

- **ExpressLinkmn**

  This unidirectional logical link represents connectivity between two degrees of a ROADM, where number m is the degree # of the FROM degree (i.e., CTP-Tx logical port), number n is the degree # of the TO degree (i.e., CTP-Rx logical port). This is just a demonstration of naming convention, but it can be different based on service providers preference for example (ExpressLink-DEG1-CTP-TX-DEG3- CTP-RX). Figure 10 illustrates the three pairs of ExpressLinks between the three degrees of a ROADM node.



(a) Unique wavelengths are enforced by PCE at the CP's of CD SRG



(b) Duplicated wavelengths are allowed at the CP's of CDC SRG.

Figure 9: Distinguish SRG CP's for CD and CDC architectures

Attribute	Description	Note
srg-number	Identifier for each SRG	Data from planning
max-pp (Npp)	Maximum number of adddrop port pairs in an SRG	Data from device Model
current-provisioned-pp	Currently provisioned number of port pair in a given SRG	Data obtained from device
Wavelength Duplication	Enumerated value: • 1 – one per SRG • 2 – one per Degree	Data from planning • "One per SRG" is applied for CD adddrop group • "One per Degree" is applied for CDC adddrop group
avail-freq-maps • *map-name* • *start-edge-freq* • *freq-map-granularity* • *effective-bits* • *freq-map*	The spectrum occupation is defined by a list of available frequency maps.	Derived from device and updated by by SDN controller (freq-map)

Table 7: Attributes associated to an SRG.

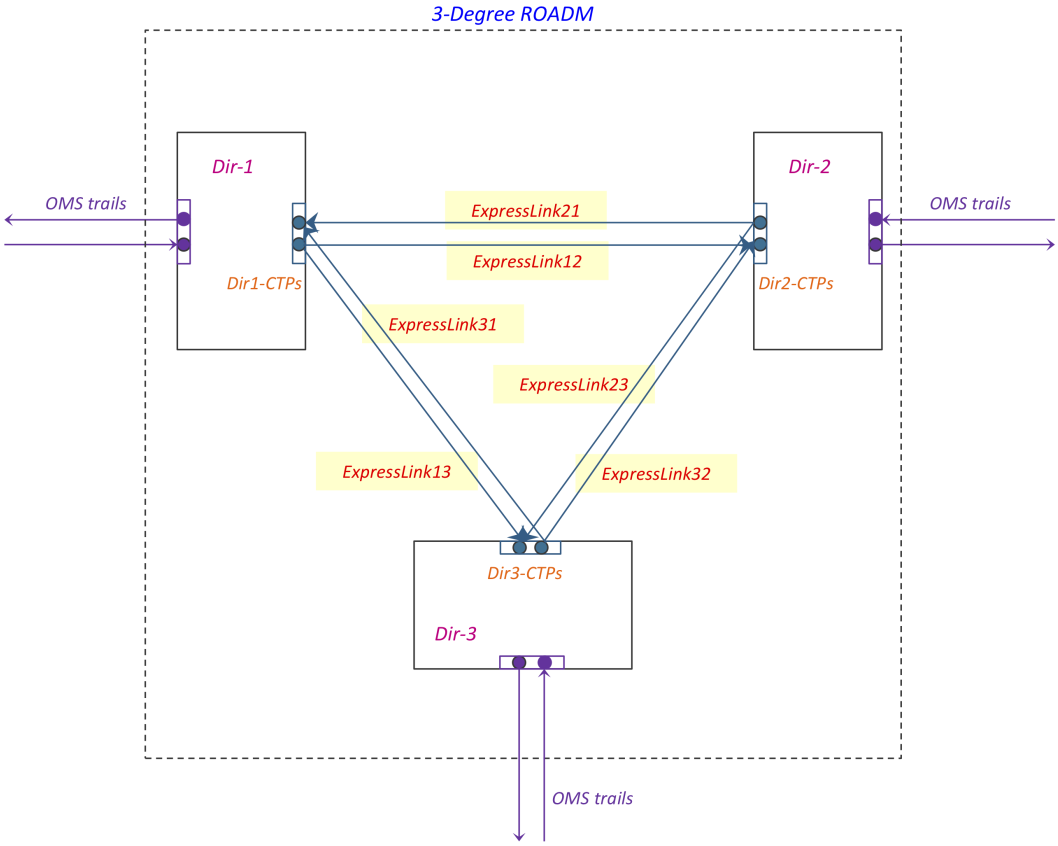


Figure 10: Logical ExpressLinks represent connectivity between ROADM degrees.

- **DropLinkxy**

  This unidirectional logical link represents connectivity between a degree and an SRG of a ROADM in the direction of traffic being dropped from the degree, where number x is the degree # where the traffic is coming FROM (i.e., CTP-Tx logical port), y is the SRG # where the traffic is going TO be dropped (i.e., CP-Rx logical port). This is just a demonstration of naming convention but it can be different based on service providers preference for example (DropLink-DEG1-CTP-TX-SRG1-CP-RX). Figure 11 illustrates the six DropLinks between the three degrees and two SRGs of a ROADM node.

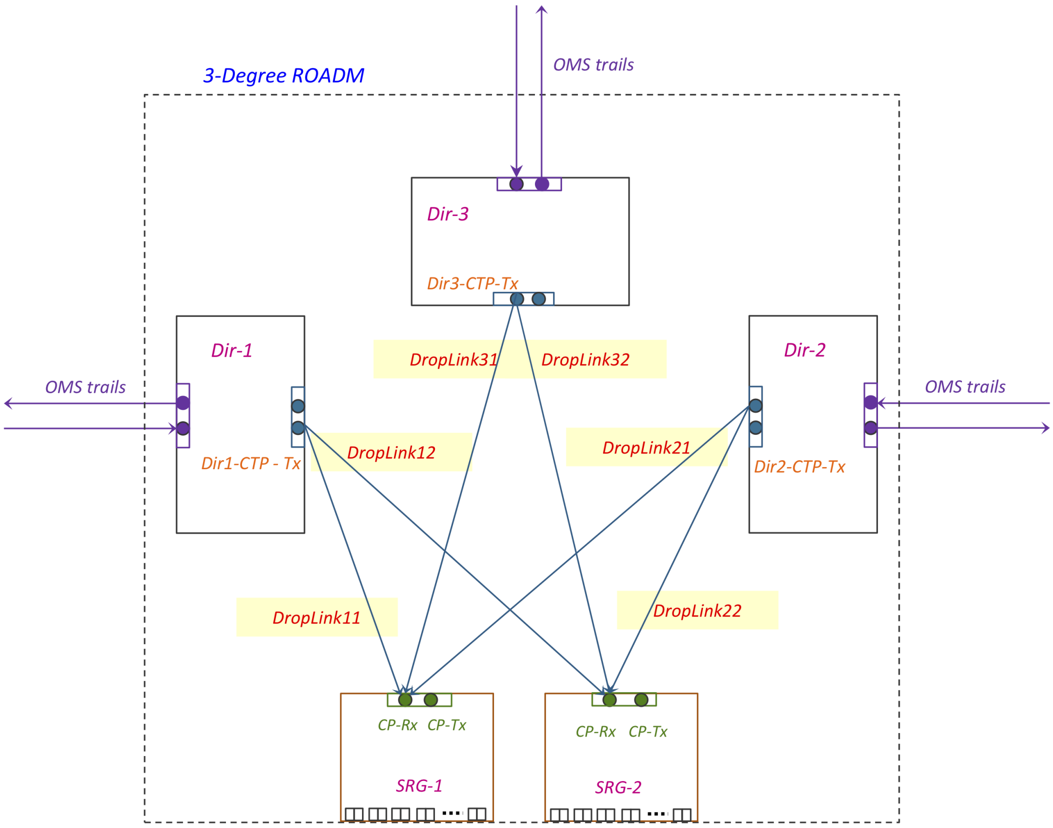


Figure 11: Logical drop links represent connectivity between ROADM degrees and SRG.

- **AddLinkyx**

  This unidirectional logical link represents connectivity between a degree and an SRG of a ROADM in the direction of traffic being added from the SRG to the degree, where y is the SRG # where the traffic is coming FROM (i.e., CP-Tx logical port) and number x is the degree # where the traffic is going TO be added (i.e., CTP-Rx logical port). This is just a demonstration of naming convention but it can be different based on service providers preference for example (AddLink-SRG1-CP-TX-DEG1-CTP-RX). Figure 12 illustrates the six AddLinks between the three degrees and two SRGs of a ROADM node.

- **ROADM-To-ROADM**

  This unidirectional logical link represents connectivity between two ROADMs. The data for ROADM-TOROADM links can be discovered by the controller based on the Link Layer Discovery Protocol (LLDP) information reported under the "protocols" subtree in the device model or can be an input from external planning system during planning phase.

- **Xponder links**

  OpenROADM topology layer will have Transponder to ROADM links and ROADM to Transponder links represented by following link types:

  – XPONDER-INPUT
  – XPONDER-OUTPUT

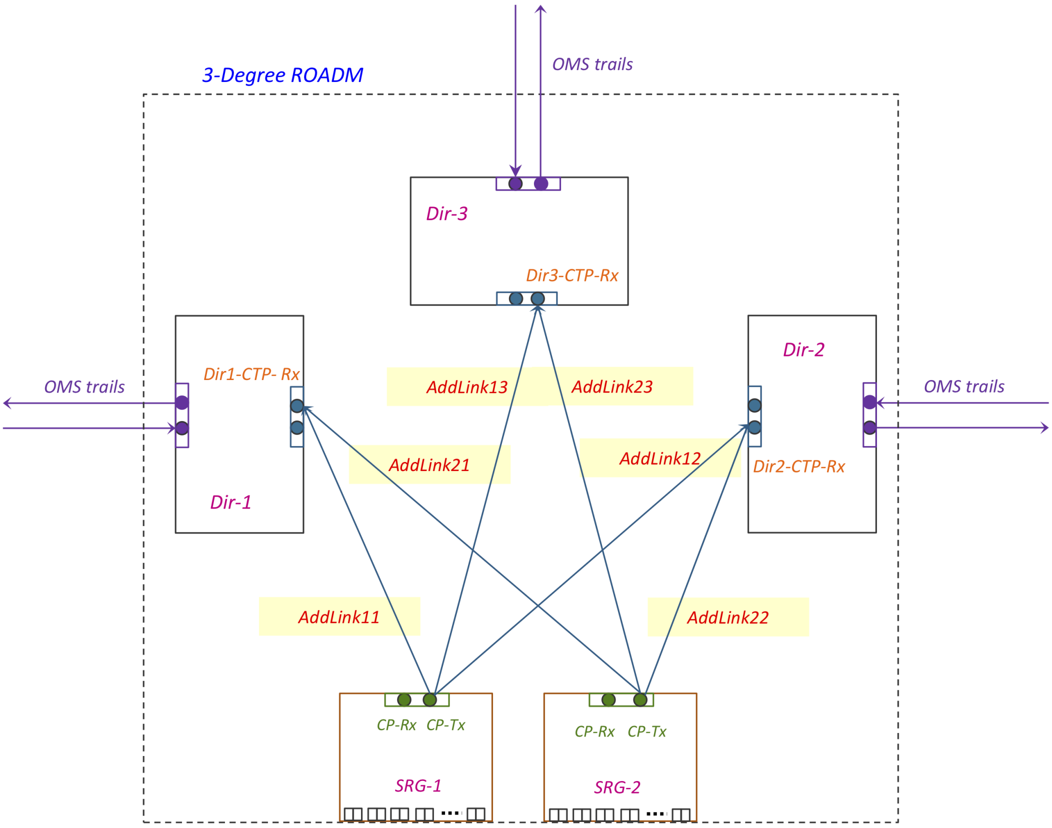


Figure 12: Logical add links represent connectivity between ROADM degrees and SRG.

Link should appear when a physical fiber connection is made between ROADM and transponder.

- **Regen links** In OpenROADM topology layer we distinguish links between xponder-SRG (XPONDER-INPUT/OUTPUT) and the links between regenerator and SRG. This allows the PCE to use any pre-deployed regenerator locations during the route-calculations.

  - REGEN-INPUT
  - REGEN-OUTPUT

  Link should appear when a physical fiber connection is made between ROADM and regenerator.

- **Turn back links** Turn back links in the network model represent the connection between the xponder-srg and srg-xponder Figure 13. The turn back functionality allows for traffic signals to be looped back on the SRG client side without transporting the signal through the ROADM transport network. The traffic arrives on one SRG port and is looped back to another SRG port within the ROADM. The two SRG ports can be on the same SRG or on different SRGs. The turn back feature was developed in support of the Open All-Photonic Network Architecture from the Innovative Optical Wireless Network (IOWN) Global Forum [3]. For further architecture details refer to the latest release of OpenROADM device model whitepaper [4].

  - TURNBACK-LINK

  Link should appear when a physical fiber connection is made between SRG-Xponder.

  The logical connectivity links are specified in a Connectivity Map in the ROADM Network Model based on input from planning. Logical links are included in the Connectivity Map of device model if and only if physical connections are planned in a node, e.g., logical express links between two degrees are not created if the two degrees are not fibered to support through traffic between them. Add link, drop link and express links are derived from device's physical linksinternal links or connection map into network model. In case the link-type is ROADM-TO-ROADM, the conditional subtree called OMS-attributes

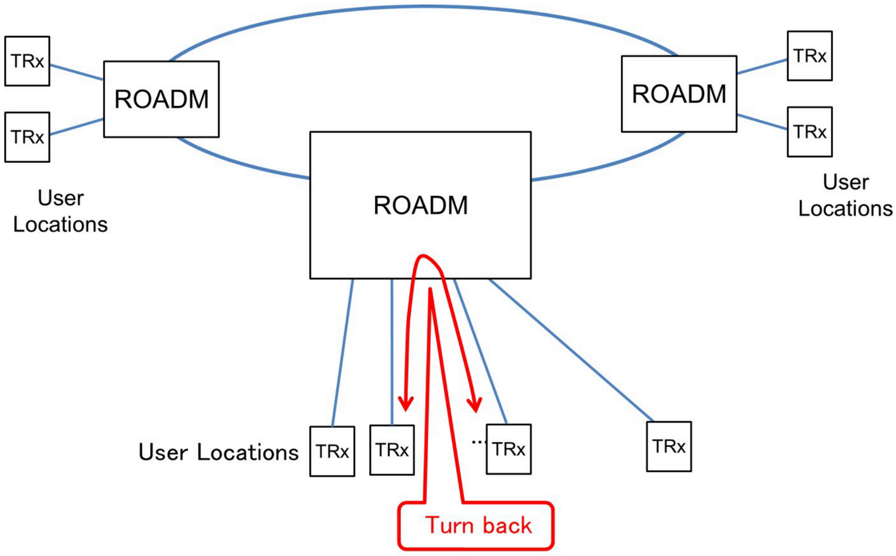


Figure 13: Turn back functionality in ROADM

appears with under the links tree. Starting from version 4.x the common attributes associated with a link such as link-type, link-length, link-latency, TEmetric, opposite links and CLFI have been moved to module org-openroadm-common-network. Attributes of the links in network model are described in Table 8.

Attribute	Description	Note
amplified	Defines whether a ROADM-TO-ROADM Link includes line amplifiers or not	
OMS-attributes	OMS-attributes is optional subtree which appears only for ROADM-to-ROADM links	

Table 8: OpenROADM network model augmentation associated to a link

The attributes for OMS-attribute subtree are displayed in the Table 9.

1.4.4 Express Wavelength Representation

The CTPs in a degree construct are used to manage servicescircuits routed through a ROADM. Physical connections between two degrees can be represented by two logical links between the CTPs. Traffic traverses through the two directionsdegrees can be described using those logical links, which are depicted in Figure 14 where two unidirectional links between the CTPs in Dir-1 and Dir-2 are shown to carry express traffic.

At each of the four connected CTP's, the wavelength assigned to a circuitservice that uses the logical links is mapped to one of the connection points that are fanned out from the CTP. This is illustrated in Figure 14 using 96 as the maximum number of wavelengths, where wavelength #4 is assigned to a wavelength level service that is express through between Dir-1 and Dir-2.

The path of the service/circuit going through between the two degrees can be represented using the two logical links depicted in Figure 14 marked as "ExpressLink12" and "ExpressLink21".

1.4.5 Add/drop Wavelength Representation

Adding and dropping wavelength-level services by a ROADM involve both directiondegree construct and SRG construct. The CTP-Tx in the directiondegree construct, which receives incoming signals from the OMS trail and feeds express channels to other directionsdegrees, can also feed add/drop wavelengths to an adddrop SRG. The CTP-Rx in the direction/degree construct, which sends outgoing signals to the OMS trail and receives express channels from other directions/degrees, can also receive adddrop wavelengths from an

Attribute	Description	Note
span	This subtree appears when the ROADM-TO-ROADM link is not amplified	Data from planning
auto-spanloss	Flag to enable/disable automatic span loss measurement, default it set to 'True'	Data from planning
spanloss-current	Current measured, updated periodically if auto-spanloss is enabled.	Set by SDN controller
spanloss-last-measured	Last measured ROADM span loss	Set by SDN controller
engineered-spanloss	Reference span loss used for the initial design	Data from external system
link-concatenation	Lists of shared risk link groups	Data from planning
SRLG-Id	Identifier for the SRLG	Data from planning
fiber-type	Type of underlying fiber	Data from planning
SRLG-length	Fiber length in meters	Data from planning
pmd	Polarization mode dispersion expressed in $ps/\sqrt{km}$	Data from external system
future-SRLGs	Lists of planned shared risk link groups	Data from planning
state-date	Date-time for the planned (future) SRLG	Data from planning
SRLG-Id	Identifier for the SRLG	Data from planning
amplified-link	This subtree appears when the ROADM-TO-ROADM link is amplified. Contains lists of section elements part which are part of the amplified links.amplified-link This subtree appears when the ROADM-TO-ROADM link is amplified. Contains lists of section elements part which are part of the amplified links. Section elements can either be an inline amplifier (ILA) or a span.	
section-elt-number	Identifier for the section element.	
section-element	Define whether a section element contains span or ILA	
ila		
amp-type	Amplifier type Data from device	
amp-gain-range	Gain range for the device between 1 and 4.	Data from device
ingress-span-loss-aging-margin	Span-loss margin used to set optical amplifier gain and output-voa. Corresponds to operator specific engineering rules. Transferred by controller to device in device OTS interface container, so that the device can set optical amplifiers parameters accordingly. Optional since it concerns only line facing amp.	Data from planning
gain	Overall Amplifier Signal gain, excluding ASE, including VOA attenuation.	Retrieved from operational value (PM)
initially-planned-gain	Overall Amplifier Signal gain, excluding ASE, including VOA attenuation. Used as a reference to track deviations out of the initial design settings, and trig warning when the settings goes out of the authorized range (Line shall be redesigned)	Data from planning tool
tilt	Tilt of smart EDFA	Data from retrieved from operational value (PM)
initially-planned-tilt	Initially planned Tilt of smart EDFA: used as a reference to keep a trace of the setting that came out of the initial design.	Data from planning tool
out-voa-att	output VOA attenuation	
eol-max-load-pIn	End Of Life Total input power at maximum load used for amplifier and VOA setting. Transferred by controller to device in device OTS interface container	Data from planning tool
egress-average-channel-power		
type-variety		
span	Span subtree defined in Table 9	

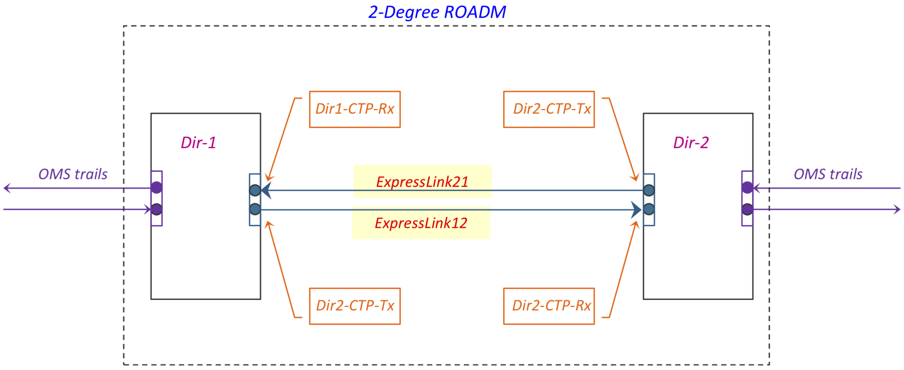


Figure 14: Logical links represent connections between two degrees of ROADM for express-through traffic.

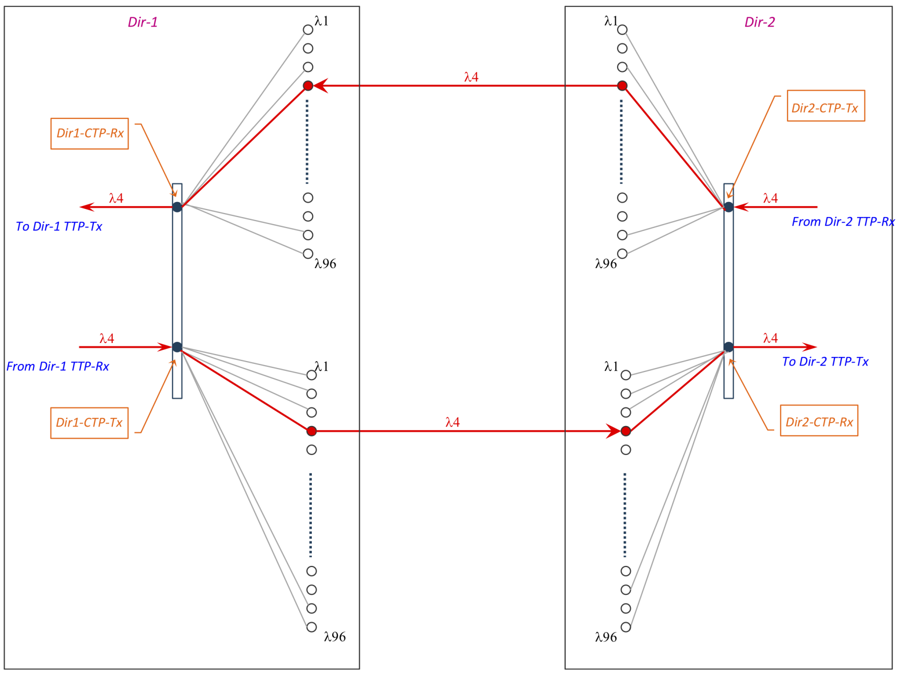


Figure 15: An express server through Dir-1 and Dir-2 using wavelength #4 (both degrees are shown).

adddrop SRG. Thus, logical links can be created between the CTPs of the directiondegree construct and the CPs of the SRG construct to support adddrop wavelengths. This is illustrated in Figure 16 where two pairs of logical links are used to represent two services supported between Dir-1 and two different SRGs. Each of the two SRGs is represented by a pair of CPs.

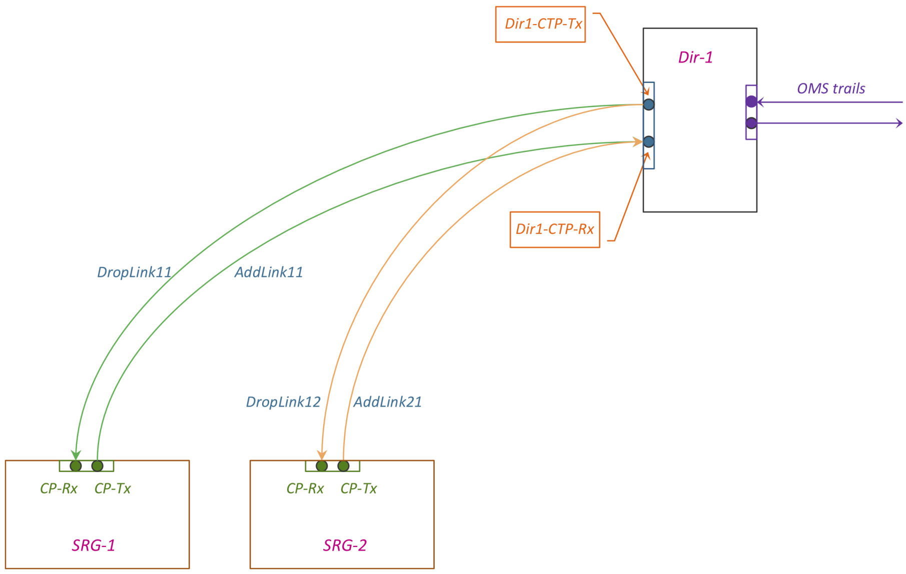


Figure 16: Logical links representing service traffic being transmitted between a Degree construct and two SRG constructs.

Each pair of CPs in an SRG construct can be logically linked to all degree constructs, e.g., the two CP pairs, representing two SRGs in Figure 17, are connected simultaneously to two separate degrees.

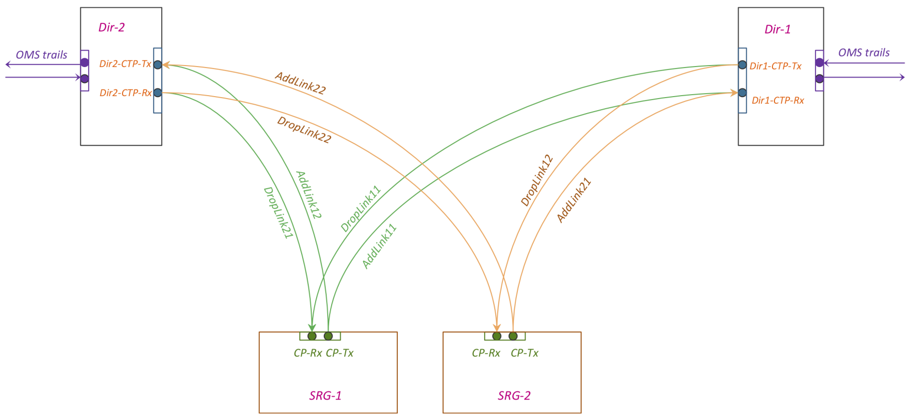


Figure 17: Logical links between two Degree constructs and two SRG constructs.

WavelengthsSpectrum supported by a CP pair must be unique if the SRG is CD equipment configuration, duplication are allowed if the SRG is CDC equipment configuration. The PCE in the Open ROADM Control Layer will enforce the rules while performing wavelength assignments.

The port pairs in an SRG that are used to connect to external devices, i.e., transponders, LGXs, pluggable units, can be pictured to be fan-out points of the CPs. Since the number of port pairs in an SRG is specific to vendor's equipment configuration, the number of fan-out points needs to be identified in vendor's Device Model. When a pair of ports in an SRG is connected to a transponder, LGX jacks, or a pluggable unit, the corresponding fan-out points in the CPs needs to reflect the connections. This way, the information on which port pair is connected to an external device is associated to the CPs and the information can be used by the PCE to determine whether there are spare add/drop ports in an SRG to support new service demands. Figure 18 shows a transponder, which is embedded in the tail construct and cabled to the 2nd port pair (IN2 and OUT2) in the SRG #1, is used for a service/circuit in degree Dir-1.

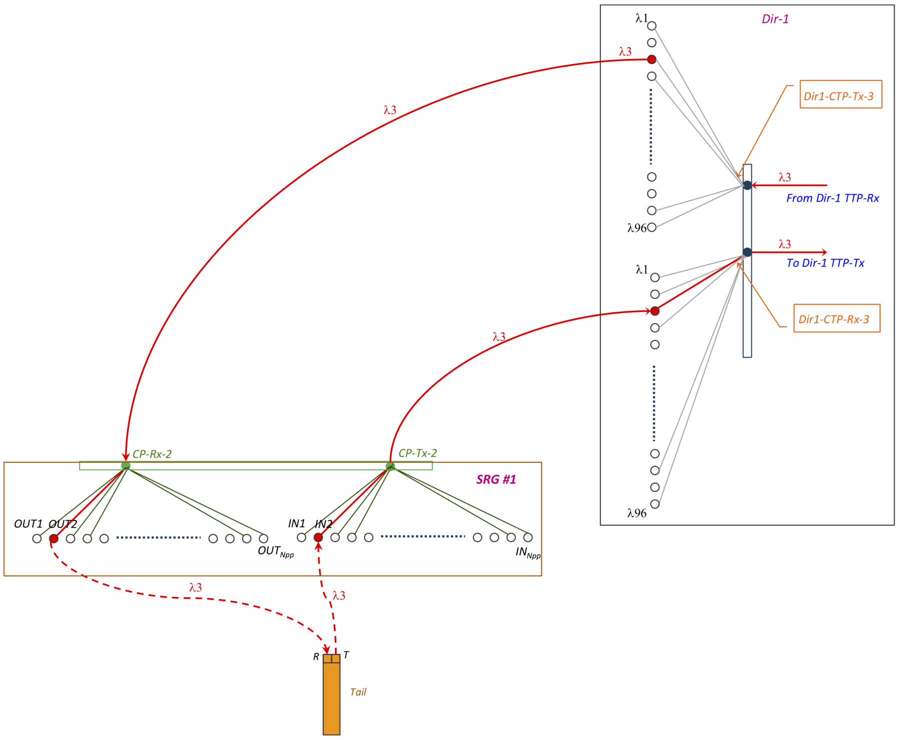


Figure 18: A service is added and dropped between Dir-1 and SRG #1.

When a servicecircuit is addeddropped through an SRG, the wavelength information (λ_3 in Figure 18) is tracked by the corresponding CTPs in the degree construct (Dir1-CTP-Tx-3 and Dir1-CTP-Rx-3 in Figure 18) and the adddrop port information (port pair #2 in Figure 18) is tracked by the CPs in the SRG construct.

1.5 OTN Topology Layer

OTN topology layer in I2RS network model holds Network information for OTN elements including Muxponders, OTN switchesswitchponders, Transponder and Regens. This layer is consisting of nodes, termination points and links.

OTN Node can be either a transponder, regen, muxponder, switchponder or OTN-switch. Within a single physical node or shelf, there can be more than one OTN element. OTN's supporting network is openroadm-network and openroadm-topology layers. Openroadm-network layer will have node level information for the whole OTN device as described in the openroadm-network layer. Openroadm-topology layer will hold supporting links for OTN-links. OTN topology layer will only have nodes of type TPDR, REGEN, REGEN-UNI, MUXPDR or SWITCH. Each node in OTN layer will have attributes described in Table 10

One OTN Node can have multiple client and network ports. A termination point in OTN topology layer can have following attributes listed in Table 11

OTN Nodes typically would be connected to each other through underlying DWDM network, although direct connections are also supported (to address, as an example, the use case where 2 switches located in the same office must be interconnected). OTN topology has OTN-links which are logical links supported by openroadm-topology layer links with following attributes (Table 12):

When a service request comes between two OTN nodes, path computation might involve setting up a service into DWDM layer. Below is the example of OTN network with existing ODU services.

OTN path computation will first validate reachability using OTN nodes and OTN links. If a path (OTN continuity) is found, the Controller shall check that the available bandwidth on the path allows the required bandwidth to be provided. If this is the case, OTN client and network ports can be set-up since DWDM network continuity already exists. If there is no path returned at the OTN layer, the Path Computation Engine (PCE) can identify connected DWDM elements using OTN tail information. PCE will need to find optimal path within DWDM network, possibly considering specific constraints in a first step. Once a WDM path is retrieved, a 100G service will be created between OTN elements to support OTN based services. This 100G service will appear as a single OTN link in the OTN layer (Figure 19).

Attribute	Description	Note
tp-bandwidth-sharing	Defines whether a ROADM-TO-ROADM Link includes line amplifiers or not	Data from device
tp-sharing-id	Unique Id to identify sharing group	Data from device
tp-list	List of termination points which are sharing BW	Data from device
shared-bandwidth	Total BW shared among list of termination points in Gbps	Data from device
possible-tp-config	Identifies the supported combinations of possible tp configuration	Data from device
config-id	Unique id for tp config	
tp-if-type-config		
tp-name	Termination point name	
tp-if-type	Supported interface capability	
otsi-rate	Optical Tributary Signal (OTSi) rate in Gbps	
switching-pools		
odu-switching-pool		Data from device
switching-pool-number	Unique identifier for each switching pool from the list	Data from device
switching-pool-type	Blocking (added constrains due to switching fabric) or Non-blocking (any port can be connected to any port)	Data from device
non-blocking-list		Data from device
nbl-number	Unique identifier for non blocking list	Data from device
interconnect-bandwidth-unit	Granularity of switch fabric	Data from device
capable-interconnect-bandwidth	Interconnect bandwidth supported by switching fabric	Data from device
available-interconnect-bandwidth	Available bandwidth for non-blocking elements	Data from device
tp-list	List of termination points which can be interconnected	Data from device
xpdr-attributes		
xpdr-number	Unique Id to identify Xpdr with in a shelf	Data from device

Table 10: Attributes of OTN topology Node

Attribute	Description	Note
tp-supported-interfaces	List of interfaces supported by termination point like 100GE, 40GE, ODU1, ODU2	Data from device
supported-interface-capability		Data from device
if-cap-type	Supported interface capability on the tp	Data from device
xpdr-tp-port-connection-attributes		
rate	Rate identity of the ODU	Data from device
odtu-tpn-pool		Data from device
odtu-type	ODTU type, part of the MSI (Multiplex Structure Identifier)	Data from device
tpn-pool	List of available Tributary Port Number (0-based), part of the MSI	Data from device
ts-pool	List of available Tributary Slots for tp	Data from device
wavelength	Attribute to be used when OTN link is using a WDM lambda.	
frequency	Frequency	
width	slot width	
tail-equipment	Type of equipment connected to the tail for example packet box	Data from planning
tail-equipment-id	Identifier of equipment connected to the tail for example client equipment ID	Data from planning
tail-clfi	Tail CLFI is available	Data from planning
tail-id	Termination point id	Set by SDN controller
network-ref	Reference to the network layer	Set by SDN controller
node-ref	Reference to the node in the network layer	Set by SDN controller
supported-client-services		
service-format	Format of the requested service: Ethernet, OTU, etc	
service-rate	Rate of the requested service in GBps. Not used when service-format=other	
other-service-format-and-rate	Used when service-format is set to other in the bookend xponder use case	

Table 11: Attributes of OTN topology termination point

Attribute	Description	Note
available-bandwidth	Available bandwidth for the link	Set by SDN controller
used-bandwidth	Total used BW for the link	Set by SDN controller
ODU-protected	ODU protection flag	Set by SDN controller

Table 12: Attributes of OTN links

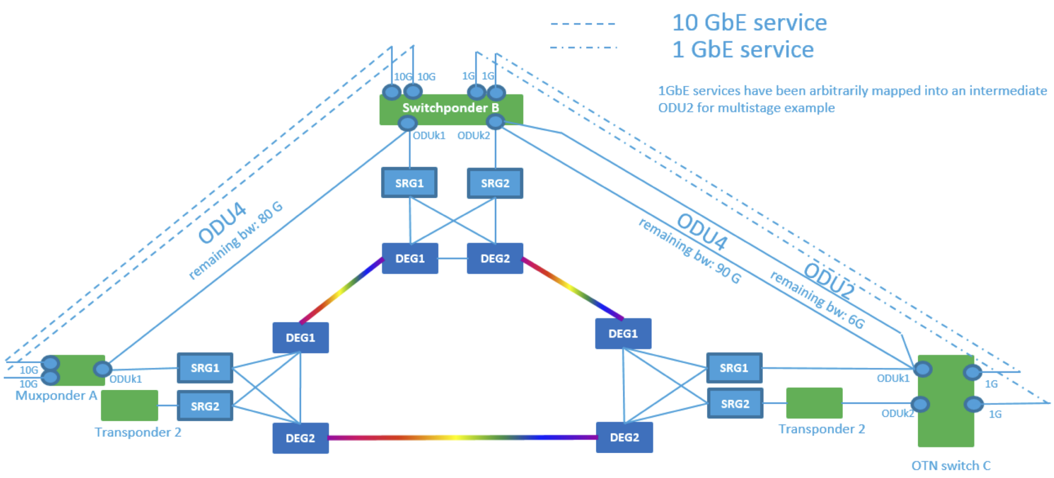


Figure 19: OTN service path computation

1.5.1 Xponder

The line side of an Xponder (transponder or muxponder) is connected to an SRG of a ROADM and the client side of the Xponder is connected to switch/router equipment through intra-office LGXs. Xponders and switch/router equipment are usually fibered to the back of LGX panels. Connections between them are then completed through jumpers inserted on the front of the LGX panels. Figure 20 shows the line-side and client-side connections of a transponder.

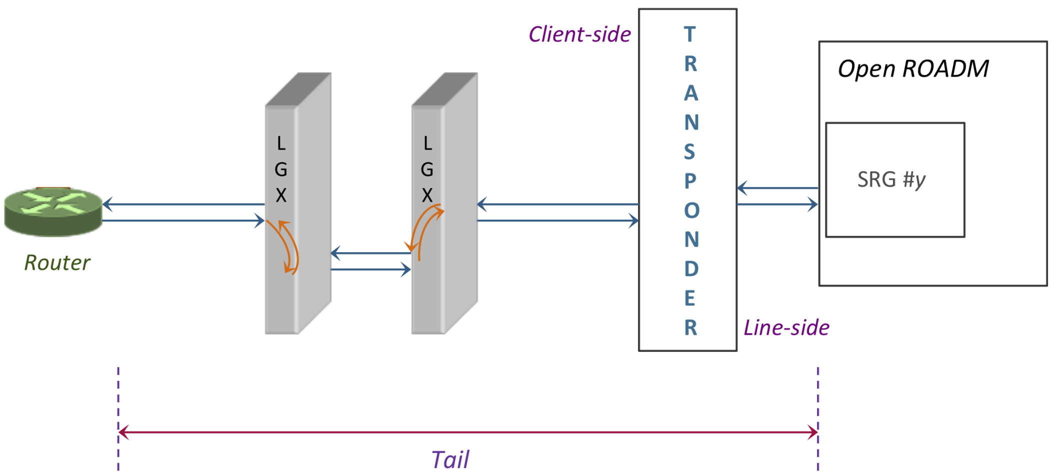


Figure 20: A transponder is used to support connection with router.

Xponder in openroadm-topology represents transponders which can have client and network port as termination point. The information associated to an Xponder in topology layer is described in Table 13.

Attribute	Description	Note
Xponder number	Unique identifier for a transponder with in a Node	Data obtained from vendor's device

Table 13: Attributes associated to an Xponder.

Equipment states for the controller are shown in Table 14.

reserved-for-facility-planned	Equipment is planned for use by a service
not-reserved-planned	Equipment is planned by not reserved for any purpose
reserved-for-maintenance-planned	Equipment is planned for use as a maintenance spare
reserved-for-facility-unvalidated	Equipment is reserved for use by a service but not validated against planned equipment
not-reserved-unvalidated	Equipment is not reserved for any purpose and not validated against planned equipment
unknown-unvalidated	Unknown equipment not validated against planned equipment
reserved-for-maintenance-unvalidated	Equipment is to be used for use as a maintenance spare but not validated against planned equipment
reserved-for-facility-available	Reserved for use by a service and available
not-reserved-available	Not reserved for use by a service and available
reserved-for-maintenance-available	Reserved as a maintenance spare and available
reserved-for-reversion-inuse	Equipment that is reserved as part of a home path for a service that has been temporarily re-routed
not-reserved-inuse	Equipment in use for a service
reserved-for-maintenance-inuse	Maintenance spare equipment that is in use as a maintenance spare

Table 14: Equipment states assigned by ROADM controller.

1.5.2 External Pluggable

Transponder is not always required between packet box equipment and ROADM. The external pluggable can be part of OTN layer as well as OpenROADM topology layer where physically connected to SRG port. Pluggable modules can be used in packet boxes to connect to adddrop groups directly, as shown in Figure 21.

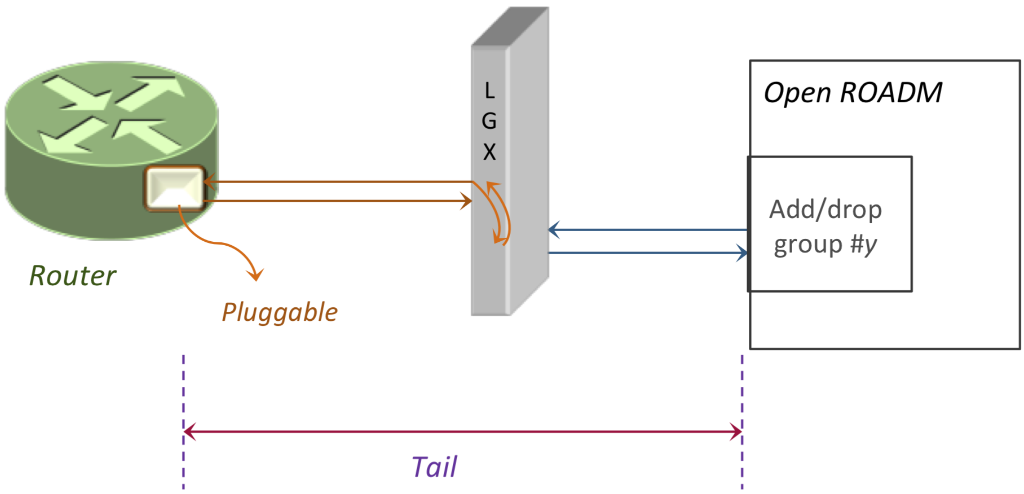


Figure 21: Connection between pluggable in router and adddrop group.

A pluggable installed in packet box equipment to interconnect with ROADM will be managed through the packet box. However, the information associated to the pluggable and described in Table 15 is made known to the Open ROADM Controller:

Attribute	Description	Note	
office	Location CLLI where the pluggable unit resides	Data from planning	
node type	Specification of the type of the node, “PLG”.	Data from planning	
pluggable number	Identifier of the pluggable unit in a given office, i.e., $1, 2, \ldots, N_p$	Data from planning	
Pluggable ID	Network-wide unique identifier for a pluggable	Constructed by concatenating office CLLI, FIC, and shelf #?	
Vendor	Identifier of the pluggable unit’s supplier	Data from planning	
Customer	Code Owner of the pluggable unit	Data from planning	
External connection	ROADM node ID		Data from planning
	SRG #		Data from planning
	Port Pair #		Data from planning
	Rate		
	Signal Format		
	Reach		
	Gray color		
	State	Pluggable module in the port can be in one of the equipment state in Table 14	
Tail	Client equipment		From SDN-C
	Client equipment ID		From SDN-C
	CLFI		From SDN-C

Table 15: Attributes associated to a pluggable in packet box.

1.6 Tail Concept and Service Model Link

1.6.1 Tail

In Figure 22, a tail facility is used to represent the connection between the port pair in an adddrop group and the router including the intermediate LGXs and transponder. This is an example which could be different for service providers. Figure 1-19 shows another intra-office tail in an example office.

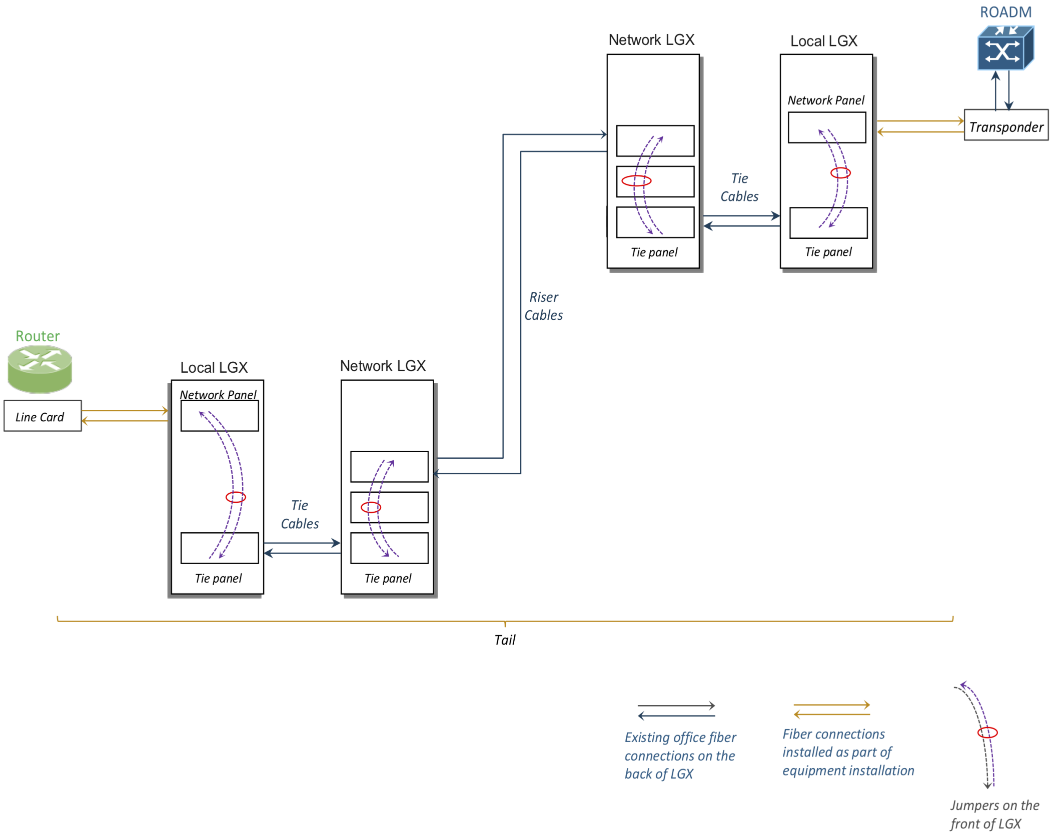


Figure 22: An intra-office tail

An intra-office tail could be further divided into two portions:

- **Client Tail**

  When a transponder or a muxponder is used between client equipment (router, switch, POITDI) and adddrop ports in ROADM SRG, a Client tail includes the client equipment, the client ports in the transponder or muxponder, and intermediate LGXs between them. Refer to Figure 23a for an example.

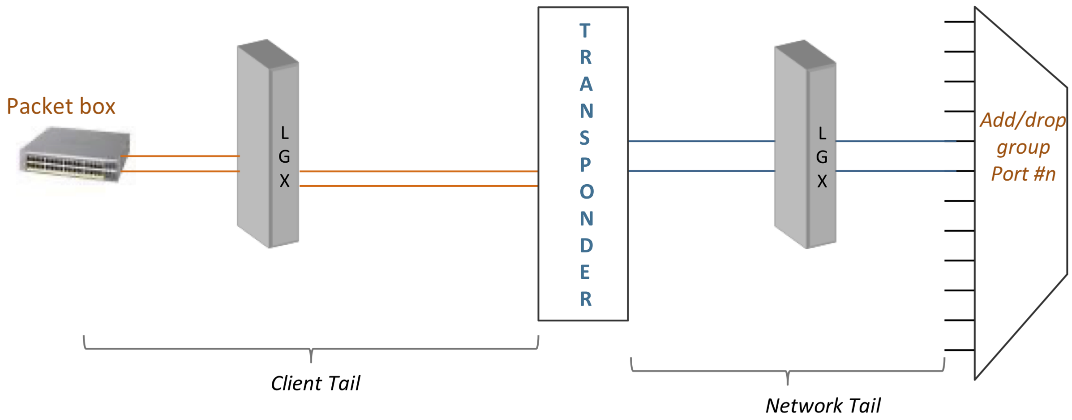
  When no transponder or muxponder is used, a Client tail becomes the entire intra-office tail, which includes the client equipment, the adddrop ports in ROADM SRG, and intermediate LGXs between them. Refer to Figure 23b for an example.

- **Network Tail** This tail exists only when a transponder or a muxponder is used between client equipment (router, switch, POITDI) and adddrop ports in ROADM SRG. It includes the line side of transponder or muxponder, the ports in ROADM adddrop group, and intermediate LGXs between them. Refer to Figure 23a for an example.

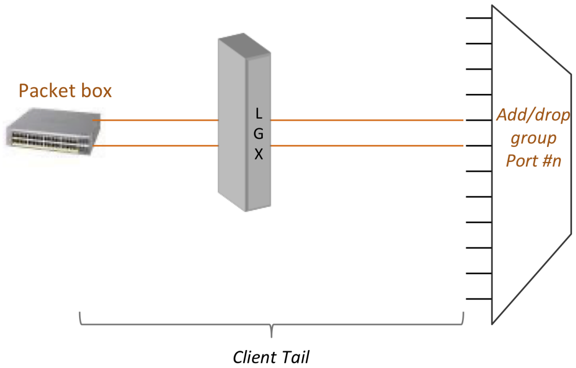
Tail models are not part of Openroadm models yet, but information below will help understand tails. The information associated to a tail facility is shown in Table 16:

1.6.2 Service/Circuit

When tail facilities exist in the offices where a service is to be terminated, the PCE in the open ROADM controller can simply use the information provided by the Network Model to compute an optimal service path



(a) Client and network tail with LGX



(b) Packet box directly connected to SRG

Figure 23: Client tail and Network tail in Metro.

Attribute	**Description**		**Note**
CLFI	Facility identifier of the tail		Data from planning
Time stamps	*Start date*		Data from planning
	End date		Data from planning
Layout	*Client equipment*		From SDN-C
	External pluggable	optional	
	List of intermediate LGXs (LGX ID + jack assignments)	optional	
	Transponder ID		From SDN-C
	List of intermediate LGXs (LGX ID + jack assignments)	optional	
	ROADM node ID		From SDN-C
	SRG #		From SDN-C
	Adddrop Port #		From SDN-C

Table 16: Attributes associated to a tail facility.

between the two tails. If tail facilities do not exist when a service request is made to the open ROADM controller, the PCE will not only compute an optimal path between two service-terminating ROADM nodes but also use the information provided by the Network Model to select proper SRGs in the ROADM nodes and, if transponders are present, identify transponders and the add/drop port pairs the transponders are connected to. The PCE can use the span loss information in the Network Model to find the shortest path for the service, use fiber span information to perform constrained routing, use the fan-out points in the TTPs and CTPs to make wavelength assignments, and use the fan-out points in the CPs to make adddrop SRG selections. A service or circuit at wavelength-level consists of one or more OMS sections. The service is terminated on client equipment connected to ROADM nodes directly or through transponders. A service is represented using six facilities, assuming a transponder is present:

- A client tail facility and a network tail facility in service's A-end
- A client tail facility and a network tail facility in service's Z-end
- A "ROADM facility" between the adddrop ports including all of the OMS trails and cross-connects
- An overall service facility between the client equipment, which encompasses the four tail facilities and the ROADM facility

Figure 24 shows the six facilities related to a service supported by three ROADM nodes in offices A, B, and C.

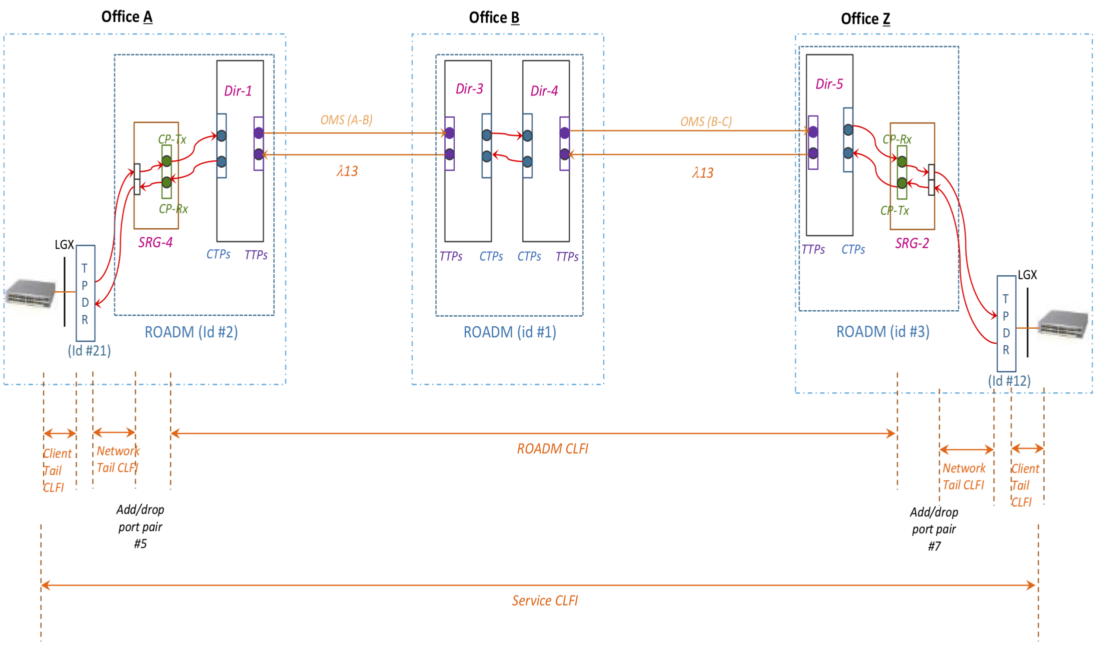


Figure 24: A service supported by three open ROADM nodes.

When tails are not pre-deployed, the information provided by the SDN Controller in the request to the Open ROADM Controller for a new service/circuit includes the attributes listed in Table 17 (not an exhaustive list):

The 'Facility CLFI' in Table 17 is the 'Service CLFI' in Figure 24. The PCE performs path computation using the network level information based on the Network Models to generate a ROADM Facility. The layout of the ROADM Facility is comprised of two ROADM nodes at the service's termination locations, intermediate OMS trails, and zero or a number of express-through ROADM nodes.

- The wavelength # used by the ROADM Facility is assigned by the PCE. The PCE manages wavelength usages of each OMS section using the TTPs terminating the OMS trails.
- The PCE also manages port pair (PP) in an SRG:
  - A pre-deployed transponder is pre-cabled to a PP in an SRG. If the PCE selects the transponder for a requested service, the transponder's PP # is then associated to the SRG's CPs and included in the service's ROADM Facility.

Attribute	Description	Note
Facility CLFI	Identifier for the servicecircuit	Data provided by SDN-C
A-end CLLI	Service's A-end office	
Z-end CLLI	Service's Z-end office	
Start date	Starting date of the servicecircuit	
End date	End date of the servicecircuit	
Routing constraints	diversity, exclude, include, co-routing, latency	

Table 17: Parameters provided by the SDN-C in a service or circuit request.

- If no transponder is available for the requested service, the PCE will selects a PP from the SRG the PCE picked for the service, associates the PP # to the SRG's CPs and include them in the service's ROADM Facility.
- The PPs in existing tail facilities are associated to their corresponding SRGs CPs. If an existing tail facility is identified in the service request, the PCE will use the PP # in the tail in the service's ROADM Facility.

Table 18 shows the layout in the ROADM Facility's A-to-Z direction.

Office A CLLI	Node ID + [SRG ID] + [CP-Tx]-[pp#]	
	Node ID + AddLink[SRG ID][Dir ID]	
	Node ID + [Dir ID] + [CTP-Rx]-[wavelength #]	
	Node ID + [Dir ID] + [TTP-Tx]-[wavelength #]	
[OMS Trail CLFI]		
Office X CLLI	Node ID + [Dir ID_1] + [TTP-Rx]-[wavelength #]	Zero or multiple express-thru ROADM
	Node ID + [Dir ID_1] + [CTP-Tx]-[wavelength #]	
	Node ID + ExpressLink[Dir ID_1][Dir ID_2]	
	Node ID + [Dir ID_2] + [CTP-Rx]-[wavelength #]	
	Node ID + [Dir ID_2] + [TTP-Tx]-[wavelength #]	
[OMS Trail CLFI]		
Office Z CLLI	Node ID + [Dir ID] + [TTP-Rx]-[wavelength #]	
	Node ID + [Dir ID] + [CTP-Tx]-[wavelength #]	
	Node ID + DropLink[Dir ID] [SRG ID]	
	Node ID + [SRG ID] + [CP-Rx]-[pp #]	

Table 18: A-to-Z Layout of a ROADM Facility maintained in the Network level.

Using the service in Figure 24, Table 19 shows the service's ROADM Facility layout in the A-to-Z direction.
In the opposite transmission direction, i.e., Z-to-A, the layout of the ROADM Facility is described in Table 20.
Using the service in Figure 24, Table 21 shows the service's ROADM Facility layout in the Z-to-A direction.
Using the service in Figure 24, Table 22 shows the tail facility in Office A.

2 Capacity and Equipment Planning

2.1 Direction/Degree

1. Planning a new degree of a ROADM involves creating an "OMS CLFI". Planner specifies new ROADM locations, ROADM node IDs, and equipment vendors in locations (CLLIs), or specifies new degrees in existing ROADM nodes.
2. Planner selects fiber type, fiber # line code to connect adjacent ROADM nodes
3. Unique OMS CLFIs are assigned to the facilities that connect ROADM nodes.

Office A CLLI	Node #2 + SRG #4 + CP-Tx–5	
	Node #2 + AddLink41	
	Node #2 + Dir-1 + CTP-Rx–13	
	Node #2 + Dir-1 + TTP-Tx–13	
OMS (A-B)		
Office B CLLI	Node #1 + Dir-3 + TTP-Rx–13	Express-thru ROADM
	Node #1 + Dir-3 + CTP-Tx–13	
	Node #1 + ExpressLink34	
	Node #1 + Dir-4 + CTP-Rx–13	
	Node #1 + Dir-4 + TTP-Tx–13	
[OMS (B-C)		
Office Z CLLI	Node #3 + Dir-5 + TTP-Rx–13	
	Node #3 + Dir-5 + CTP-Tx–13	
	Node #3 + DropLink52	
	Node #3 + SRG #2 + CP-Rx–7	

Table 19: Example of an A-to-Z layout of a ROADM Facility in the Network level.

Office Z CLLI	Node ID + [SRG ID] + [CP-Rx]-[pp#]	
	Node ID + DropLink[Dir ID][SRG ID]	
	Node ID + [Dir ID] + [CTP-Tx]-[wavelength #]	
	Node ID + [Dir ID] + [TTP-Rx]-[wavelength #]	
[OMS Trail CLFI]		
Office X CLLI	Node ID + [Dir ID1] + [TTP-Tx]-[wavelength #]	Zero or multiple express-thru ROADM
	Node ID + [Dir ID1] + [CTP-Rx]-[wavelength #]	
	Node ID + ExpressLink[Dir ID_2][Dir ID_1]	
	Node ID + [Dir ID_2] + [CTP-Tx]-[wavelength #]	
	Node ID + [Dir ID_2] + [TTP-Rx]-[wavelength #]	
[OMS Trail CLFI]		
Office Z CLLI	Node ID + [Dir ID] + [TTP-Tx]-[wavelength #]	
	Node ID + [Dir ID] + [CTP-Rx]-[wavelength #]	
	Node ID + AddLink[SRG ID][Dir ID]	
	Node ID + [SRG ID] + [CP-Tx]-[pp #]	

Table 20: Z-to-A Layout of a service maintained in the Network level.

Office Z CLLI	Node #3 + SRG #2 + CP-Rx–5	
	Node #3 + DropLink25	
	Node #3 + Dir-5 + CTP-Tx–13	
	Node #3 + Dir-5 + TTP-Rx–13	
OMS (B-A)		
Office B CLLI	Node #1 + Dir-4 + TTP-Tx–13	Express-thru ROADM
	Node #1 + Dir-4 + CTP-Rx–13	
	Node #1 + ExpressLink43	
	Node #1 + Dir-3 + CTP-Tx–13	
	Node #1 + Dir-3 + TTP-Rx–13	
[OMS (C-B)]		
Office A CLLI	Node #2 + Dir-1 + TTP-Tx–13	
	Node #2 + Dir-1 + CTP-Rx–13	
	Node #2 + AddLink14	
	Node #2 + SRG #4 + CP-Rx–7	

Table 21: Example of an Z-to-A layout of a ROADM Facility in the Network level.

CLFI Tail	facility CLFI
Start date	*November 1, 2016*
End date	*January 1, 9999*
Packet box	*#1*
Transponder ID	*#21*
LGX frame 3-1-36	*LGX frame 3-1-36*
ROADM ID #2	*ROADM ID #2*
SRG #4	*SRG #4*
Port pair #5	*Port pair #5*

Table 22: Example of a tail facility.

4. Equipment Engineer assigns HS LGX jacks for each new ROADM directiondegree to make connections to the OSP fiber.

The information described in Section 1.4.1 for a ROADM node and a directiondegree can be derived from steps (1) and (3) above.

Note: Fiber spans, or Facility_Routing_Subpath, associated to each OMS CLFI are assumed to be recorded in the SRLG Database through an external application which identifies SRLGs for all Metro network facilities. The SRLG data is required for the PCE to perform constrained routing.

2.2 Add/Drop Group and SRG

To add an adddrop group or an SRG to a ROADM node, planner specifies an ID (#) to the planned adddrop group or SRG in a planned or existing ROADM node. Vendor of the add/drop group or SRG is the same as the vendor of the ROADM degrees. The information described in Section 1.4.2 for an add/drop group can be derived as mentioned above.

2.3 Transponder

1. To add transponder to an adddrop group in a planned or an existing ROADM node, planner specifies an ID (#) to the planned transponder, identifies the ROADM node ID and the adddrop group (or SRG) # the transponder's line side is connected, and Customer Code.

2. To add pluggable unit to a planned or existing transponder, planner specifies the ID of the transponder and the vendor and type of the pluggable unit.

3. Equipment Engineer assigns port pair# in the adddrop group (or SRG) specified by planner to connect to the lineside of the planned transponder. The information described in Section 1.5.1 for a transponder can be derived from the steps above.

2.4 External Pluggable

1. To add pluggable in a router and connect it to an adddrop group in a planned or an existing ROADM node, planner specifies an ID (#) for the planned pluggable, identifies the ROADM node ID, and the add/drop group # the pluggable is connected to.

2. Equipment Engineer assigns office LGX jacks for connection between the pluggable and the adddrop group specified by planner, including the port pair # in the adddrop group. The information described in Section 1.5.2 for an external pluggable can be derived from step (1) and (2) above.

2.5 Tail

1. L0 and L2, L3 planners together determine where tail facilities should be created.

2. Per input from planners, equipment engineer creates a "tail CLFI" to represents the intra-office connection between client equipment and a ROADM's adddrop ports.

The information described in Section 1.5for a tail facility can be derived from step (2) above.

Note: Some Service Providers may decide to not pre-deploy transponders and pre-build tails. Thus, depending on how a service path is computed by the PCE in the Open ROADM Controller, required equipment will then be ordered, installed, and provisioned for the service.

3 Path Computation

The topology of the ROADM network can be constructed using the ROADM degreesdirections inventoried in the Open ROADM Topology Layer. The adddrop capabilities in each ROADM can be derived from the adddrop groups inventoried in the Open ROADM Topology Layer. An example of a 4-node ROADM network is shown in Figure 25.

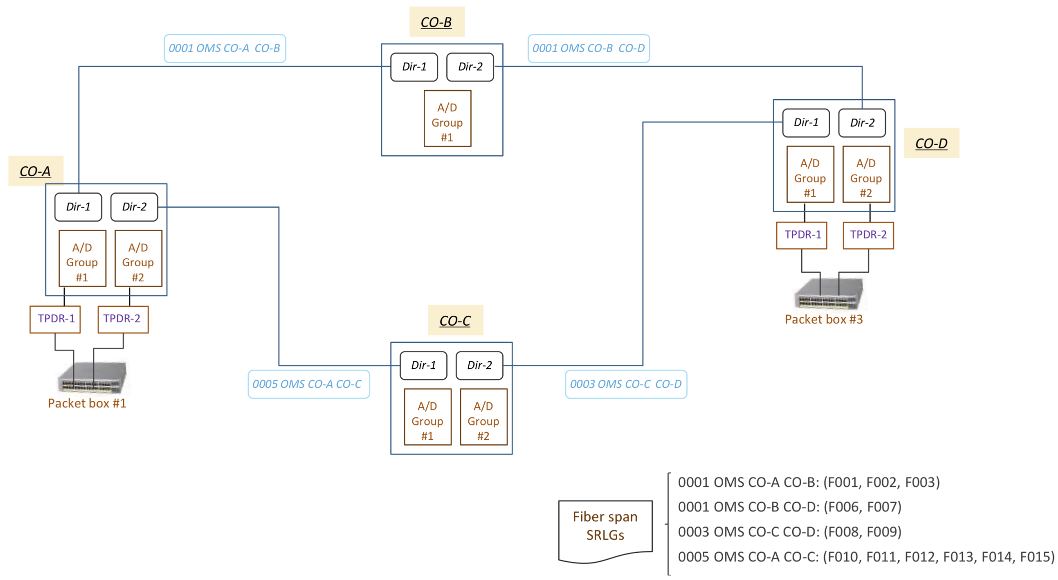


Figure 25: Topology of a 4-node ROADM network.

The fiber spans of each OMS section need to be made known to the Open ROADM Topology Layer. Those fiber spans corresponding to the OMS's (for example, those shown in in Figure 3 1) are stored in the SRLG (Shared Risk Link Group) Database along with fiber spans that are associated to embedded services that are either in the open ROADM network or outside of the open ROADM network. The SRLG Database is used by the PCE (Path Computation Element) in the Open ROADM Control Layer to compute paths for service demands that have routing constraints, e.g., diversity, exclude, include, etc. When transponders are planned and deployed, they are also inventoried in the Open ROADM Topology Layer. Pre-deployed transponders can then be pre-cabled to switchrouter equipment and represented by tail facilities. The tail facilities must be made known to the SDN Controller and the Open ROADM Topology Layer so that the SDN Controller can request links between existing tails and the PCE can calculate service paths between specified tails. Figure 26 shows four tails (two in CO-A and two in CO-D) are pre-deployed in the 4-node ROADM network.

PCE receives service request from the SDN Controller and perform service path computation. Routing constraints imposed on the requested service must be considered by the PCE to find an optimal route for the service demand. Figure 27 shows two diverse services routed in the 4-node ROADM network.

After the two services are provisioned in the network, the SRLG Database is updated with the fiber spans corresponding to the two services, as shown in Figure 3 3. Note: The SRLG Database contains fiber spans associated to services routed outside of the open ROADM network. This is necessary because routing constraints may be referred to services routed either inside of outside of the open ROADM network. Routing constraints cannot be neglected by the Open ROADM Topology Layer to make equipment assignment for new services. For example, the diverse constraint requires services to be assigned to tails that are connected to different adddrop groups. Conversely, the co-routing constrain requires services to be assigned to tails that are connected to the same adddrop group. A service in the ROADM network can be specified with a start date and end date, which are to be used by the Open ROADM Topology Layer to turn up the service and remove the service, respectively.

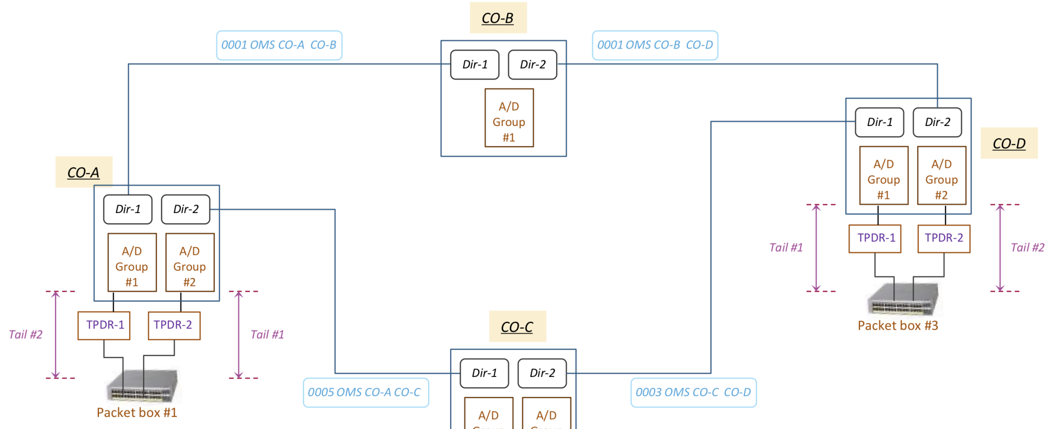


Figure 26: Tails are pre-deployed in the ROADM network.

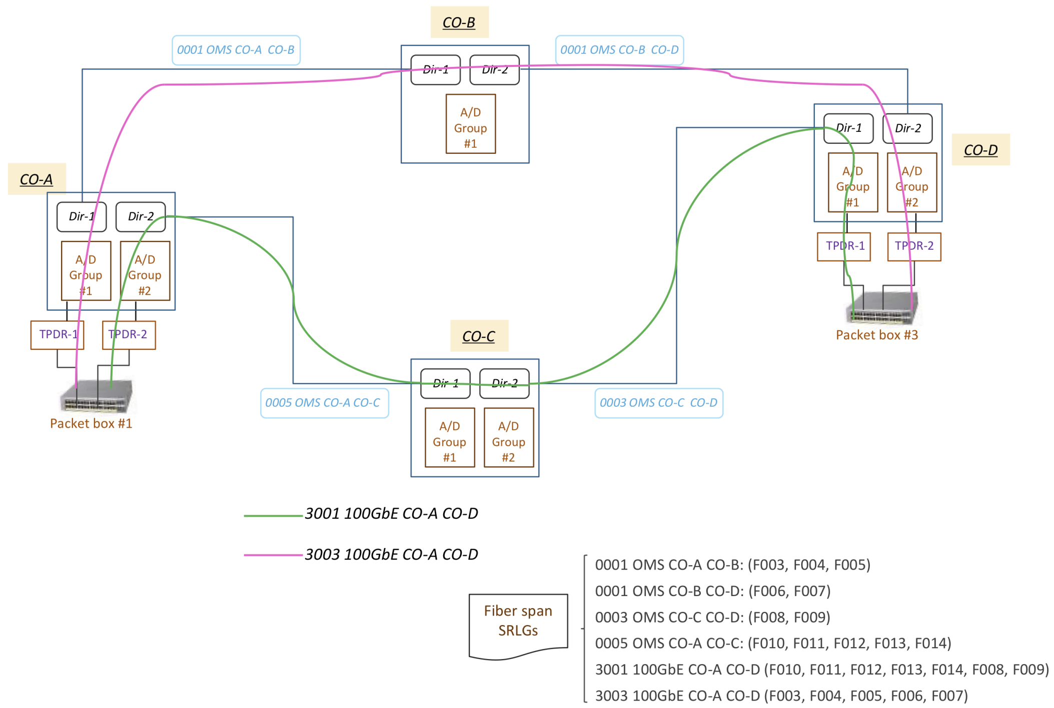


Figure 27: Two diverse services routed in the ROADM network.

4 Information Consolidation Between Network Model and Device Model

The Open ROADM controller needs circuit pack level information to perform some management functions, e.g., fault isolation, power monitoring, etc. Since vendor specific equipment configuration is supposed to be specified in vendor's Device Model, the Device Model must be built in such a way that the representation of ROADM in the Network Model is an accurate and abstracted view of the ROADM that is detailed in the Device Model. The TTPs, CTPs, and CPs in the Network Model should have corresponding physical ports in circuit packs that are described in the Device Model and perform precisely the functions the physical equipment does. This way, the information at circuit pack level can be easily obtained from the Device Model [4].

For example, if vendor's Device Model maps the optical amplifiers transmit and receive ports to TTP-Tx and TTP-Rx and some physical ports in the directional WSS (branching WSS or line WSS) to CTP-Rx and CTP-Tx and specifies the circuit packs and physical connections between the circuit packs, the actual equipment layout of a service that is represented at the network level between TTP and CTP can be derived from the vendor's Device Model. Similarly, by deriving the layout between the CTP and CP and layout between the CP from the Device Model, the abstracted layout of a service at the network level in Table 1 18 and Table 1 20 can be converted to a complete layout of actual equipment.

4.1 ROADM

1. Detailed equipment configurations shall be modeled in such a way that the required inventory data related to a degree can be generated automatically when it is instantiated.

    - The circuit packs associated to the degree are generated from planning data. Validation of degree # is supported by the model, i.e., whether degree # exceeds the capability of vendor's ROADM product.
    - The bay FIC and AIDs (bayshelfslots, U# in a rack, etc.) of the circuit packs are expected to be provided by a capacity planning tool based on engineering rules. The bay FIC and AIDs will be specified in the instantiation request so that the bay FIC and AIDs can be populated as attributes of the equipment instances that are generated automatically based on vendor's Device Model. Note: The bay FIC and AIDs should be provisioned in the NE and retrievable from the NE. Validation of bayshelf? Bayshelf information is in the planning system, not in the NE
    - Physical connections between the circuit packs are created based on planned device template. Physical connections must reflect precisely the cabling between physical ports in the circuit packs, e.g., in Table 23

Physical Connection Name	Source Port	Destination Port
Dir-TLink	Dir2-WSS-Tx	Dir2-TxAmp-IN
Dir-RLink	Dir2-WSS-Rx	Dir2-RxAmp-OUT

Table 23: Physical Connections

    Type – workstep marking for external connections vs. non-workstep marking for internal connections

    - Internal links between circuit pack's in and out ports are created automatically. Figure 28 shows the internal links inside a 1x9 WSS where the 9 links between the Tx port and the 9 input ports are identified and the 9 links between the Rx port and the 9 output ports are identified.
    - Interconnections with all existing directions/degrees are generated automatically.
    - Interconnections with all existing add/drop groups are generated automatically
    - The following physical ports should have attributes specifying which logical points in the Network Model the physical ports are mapped to:
        - The physical port in a given degree through which the outgoing signal to another ROADM is launched.
        - The physical port in a given degree through which the incoming signal from another ROADM is received.
        - The physical ports in a given degree through which express traffic going to other degrees of the same ROADM is transmitted.

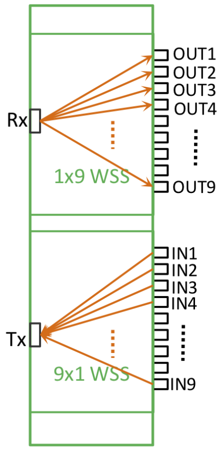


Figure 28: Internal Links inside a WSS.

- The physical ports in a given degree through which express traffic coming from other degrees of the same ROADM is received.
- The physical ports in a given degree through which add/drop traffic going to all adddrop groups is transmitted
- The physical ports in a given degree through which add/drop traffic coming from all adddrop groups is received
- OMS CLFI written in the node and associated to the equipment
- Alarm messages should include the facility CLFIs

- Detailed equipment configurations shall be modeled in such a way that the required inventory data related to an add/drop group or an SRG in an add/drop group can be generated automatically when it is instantiated.
  - The circuit packs associated to the adddrop group or the SRG in an existing adddrop group are generated automatically. Validations of add/drop group # and SRG # in an add/drop group are supported by the model, i.e., whether the specified degree # or SRG# in an existing adddrop group exceeds the capability of vendor's ROADM product.
  - Each circuit pack in a given add/drop group can be identified with the specific add/drop group number and the SRG number, e.g., "ADG2-SRG3" (the 3rd SRG in the 2nd adddrop group).
  - The bay FIC and AIDs (bay/shelf/slots, U# in a rack, etc.) of the circuit packs are expected to be provided by a capacity planning tool based on AT&T engineering rules. The bay FIC and AIDs will be specified in the instantiation request so that the bay FIC and AIDs can be populated as attributes of the equipment instances that are generated automatically based on vendor's Device Model.
    Note:
    * The bay FIC and AIDs should be provisioned in the NE and retrievable from the NE.
    * Validation of bayshelf? Bayshelf information is in the planning system, not in the NE. Physical connections between the circuit packs are created based on planning input. Physical connections must reflect precisely the cabling between physical ports in the circuit packs.
- Internal links between circuit pack's in and out ports are created automatically.
- Interconnections with existing directions/degrees are generated based on planning input. Those physical connections between ROADM degrees and between ROADM degrees and SRGs are one-to-one mapped to logical connectivity links described in Section 1.4.5.
- Query for the # of fan-out ports in each SRG, i.e., the # of TxRx ports supported by each SRG.# of TxRx ports can be increased incrementally. This can be self discovered.
- The following physical ports should have attributes specifying which logical points in the Network Model the physical ports are mapped to:
  - The physical ports in a given SRG in a given add/drop group through which adddrop traffic going to all ROADM degrees is transmitted

  - The physical ports in a given SRG in a given add/drop group through which adddrop traffic coming from all ROADM degrees is received
- Descriptive metadata:
  - Vendor
  - # of wavelengths in OMS trails
  - Maximum # of directionsdegrees
  - Maximum # of adddrop groups
  - Type of adddrop group, CD vs. CDC
  - Maximum # of SRGs in an add/drop group.
  - Maximum # of TxRx port pairs in an SRG

4.2 Transponder

1. A transponder shall be modeled in such a way that the required inventory data related to the transponder can be generated automatically when it is instantiated.
   - The transponder circuit pack is generated based in planning input.
   - The following values specified in the instantiation request are populated as attributes of the transponder instance.
     - Location CLLI
     - ID assigned to the transponder
     - AIDs (bayshelfslots) of the transponder
     - Line side connections, e.g., LGX jack #s, adddrop group port pair.
   - Internal links between circuit pack's in and out ports are created automatically.
   - Descriptive metadata:
     - Vendor
     - Signal rate
     - SRG for multiple transponders on the same blade

4.3 Pluggable Module

1. A pluggable module shall be modeled in such a way that the required inventory data related to the pluggable module can be generated automatically when it is instantiated.
   - The pluggable module instance is generated based on planning input.
   - The following values specified in the instantiation request are populated as attributes of the transponder instance:
     - Location CLLI
     - ID assigned to the pluggable module
     - AIDs (bayshelfslots) of the pluggable module
     - Line side connections, e.g., LGX jack #s, adddrop group port pair.
2. Descriptive metadata:
   - Vendor
   - Signal rate

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