TELECOM INFRA PROJECT

TIP OOPT MUST Optical Whitepaper

Target Architecture: Disaggregated Open Optical Networks

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Introduction

The open and disaggregated optical systems enable the operators to manage multi-vendor networks and to pick the most suitable open terminals from arbitrary vendors.

Examples of drivers for the disaggregation are:

- select the most suitable technology
- select the best offers
- decouple the life cycle of Optical Line System and transponders.

1. Introduction

The open and disaggregated optical systems enable the operators to manage multi-vendor networks and to pick the most suitable open terminals from arbitrary vendors. Examples of drivers for the disaggregation are:

- select the most suitable technology
- select the best offers
- decouple the life cycle of Optical Line System and transponders.

The focus of TIP Open Optical Packet Transport (OOPT) subgroup program ecosystem, on defining an open environment for optical networks, is illustrated in Figure 1.

- The CANDI working group builds the use cases and sets the expectations on the Open-Optical Networks.
- The MUST working group (WG) defines SDN reference architecture, prioritizes and specifies the implementation requirements for the selected use-cases, detailing best suited standard interfaces, protocols, and data models.
- The PSE WG assures optical impairment validation function.
- The DOS WG defines new Open Terminals and Open Optical Line System disaggregated products to fit operator requirements in the overall architecture.

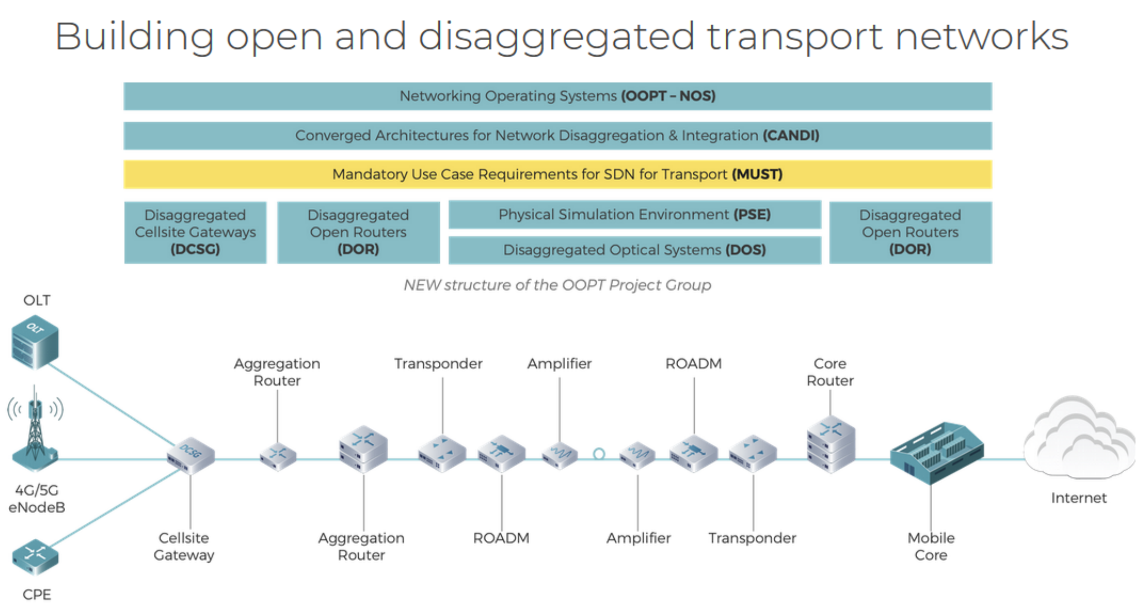


Figure 1. TIP OOPT disaggregated transport network.

This paper provides the TIP OOTP MUST target architecture for disaggregated open optical networks. We describe the meaning of "Open", the functions associated with the use cases and the degree of “Disaggregation” of the monolithic transport optical system. The main sections of this white paper will discuss Open-Optical Terminals (O-OT), focusing on Open-Optical Line Interfaces (O-OLI), Open-Optical Line Systems (O-OLS), Open-Planning and Impairment Validation (O-PaIV) and the management guidelines via SDN and APIs.

This paper is co-signed by the following operators:

- Deutsche Telekom
- MTN
- Orange
- Telefónica
- Telia Company
- TIM
- Turkcell
- Vodafone

1.1 Terminology

In this document the following terms are employed with the definitions specified below:

- **Open**: Generally, when this term is prefixed to a target (e.g. an Open Line System, O-OLS), it implies that the target (system, piece of equipment, software (SW), network function, etc.) exposes interfaces, often Application Programming Interfaces (API), with a well-known and standard protocol, model and rules for use for the integration by the Operators in their networks and OSS/BSS systems. These interfaces are specified by MUST. The specific meaning of this attribute, as applied to an architectural component, is clarified and extended in the relevant specific chapters within this document.
- **Network Element (NE)**: in this context, an NE is a piece of equipment, housing homogenous network functions, possibly made by several shelves or blades, but seen by Management & Control systems (i.e. SDN Controllers), as a single management entity through a suitable API, often termed South Bound Interface (SBI).

- **Optical Transport Network**: identifies a complete set of NEs, interconnected by optical fibres in a specified topology (e.g., mesh, linear chain, point to point), a control & management software and all the associated functionalities, allowing a transport service of selected digital clients adapted on DWDM media channels.

  Depending on application and topology, an Open Transport Network could include all, or a suitable subset of the following types of NEs:

  - **Optical Terminal (OT):** NEs that constitute the digital to WDM adaption layer being in charge of the adaption of digital client signals to analogical "media channels". OTs are mandatory in any optical transport network. (See below for a more detailed definition)
  - **Reconfigurable Optical Add Drop Multiplexer (ROADM)** NEs include optical switching, amplification, equalization and possible Add&Drop optical functions.
  - **Mux/Demux** NEs are a single line side optical multiplexer/demultiplexer often fitted with colourless functionalities. This network element is common in linear chain topology at both ends of the chain and in point-to-point topologies.
  - **In-Line Optical Amplifier (ILA)** NEs are inserted in a long transmission fiber span, between Mux/Demux NEs or ROADM NEs, to recover optical attenuation.

- **Open-Optical Network (O-ON)**: we defined the MUST view of the O-ON concept as an Optical Transport Network which complies with the "open" and "disaggregation" requirements described within all document sections. In the partially disaggregated architecture, it consists of O-OLSs and O-OTs.
- **Optical Terminal (OT)**: in the context of this document, the term designates a category of NEs in an Optical Transport Network, including the network functions of Transponders (1:1 mapping of clients to line side interfaces); Muxponders (N:1 mapping and multiplexing); Switchponders (N:M mapping, digital switching and multiplexing). Their role is to adapt digital clients of the Optical Transport Network over DWDM channels. Sometimes, in the document, the term 'Legacy Terminal' is used instead of Optical Terminal to refer to the same.
- **Open-Optical Terminal (O-OT)**: this term as defined in this paper, extends the definition of Optical Terminal to all the categories of devices housing Open Optical Line Interfaces (O-OLIs), which fulfils the set of requirements, also included in this document. In summary, these are: the support of Open and Standard management interfaces; the standalone deployment and management, independently from the Open Optical Line System (O-OLS). An O-OT adapts digital clients and generates one or more "alien wavelength" optical DWDM channels to be transparently transported by one, or a chain of O-OLS.
- **Optical Line System (OLS)**: the optical transport network segment that exclusively supports optical analogical DWDM channels as clients.

- **Open-Optical Line System (O-OLS)**: a complete and autonomously managed optical transport network also supporting (together with digital clients), or exclusively supporting optical analogical DWDM channels as clients. In the context of this document, the term “open” refers to the fact that an O-OLS allows, as analogical clients, any signal which follows a given behaviour, specified by the O-OLI definition in this document. It exposes a programmable NBI API complying with specification herein.
- **Open-Optical Line Interface (O-OLI)**: in the context of “partial disaggregation”, as defined in this document, an O-OLI specifies the physical and logical single optical DWDM channel interface between O-OTs and O-OLS. An O-OLI is therefore the functional and administrative demarcation point between an O-OLS and the set of O-OTs generating the analogical “alien wavelength” channels. O-OLI provides all the required physical, control and management information to allow and adapt “alien wavelengths” and possible OTN capabilities over the O-OL for aggregated optical transport network. The specification of O-OLI is a major target of this white paper.
- **Open-Planning and Impairment Validation (O-PaIV):** an open planning functionality which provides: (1) OLS network design and (2) verification of EoL margins for connections (wavelengths) between optical line interfaces. This definition implies that any third party can perform (1) and (2), since necessary data is shared by the O-OLS and the O-OLI vendors.

2

Open Optical Networks, OON

The transport networks can be divided into different domains, for example vendor domains, technology domains, optical domains, geographical domains, and operator domains. Open-Optical Networks (O-ON) aim to enable more efficient DWDM network architectures...

2 Open Optical Networks, OON

2.1 Function

The transport networks can be divided into different domains, for example vendor domains, technology domains, optical domains, geographical domains, and operator domains. Open-Optical Networks (O-ON) aim to enable more efficient DWDM network architectures with enhanced management of multi-domain networks, by providing flexible combinations of network elements from different vendors (disaggregation) and open end-to-end control and management based on standard SDN architecture. In this paper, the target scenario is a single operator domain with possible multiple vendor domains, including meshed networks as well as point-to-point DCI.

The rapid rate of innovation in coherent DWDM transponders (on average every 2 years), triggers the operators' need to decouple the DWDM line systems (with an average lifecycle of 10 years) from the transponders/muxponders deployment, to take advantage of the best and most cost-efficient technology when it becomes available.

To disaggregate the DWDM systems into the building blocks: O-OTs (see section 3 for a complete definition), and O-OLS (section 4), is a priority objective for operators. The number of vendors with integrated DWDM systems have been reduced over the years due to consolidations and changed focus. The O-ONs and disaggregation strategies can compensate for this, by reducing the single vendor deployments, and facilitate competition by stimulating new business opportunities.

The disaggregation gives the operators the possibility to mix and match O-OLIs, produced by different suppliers, over the same O-OLS.

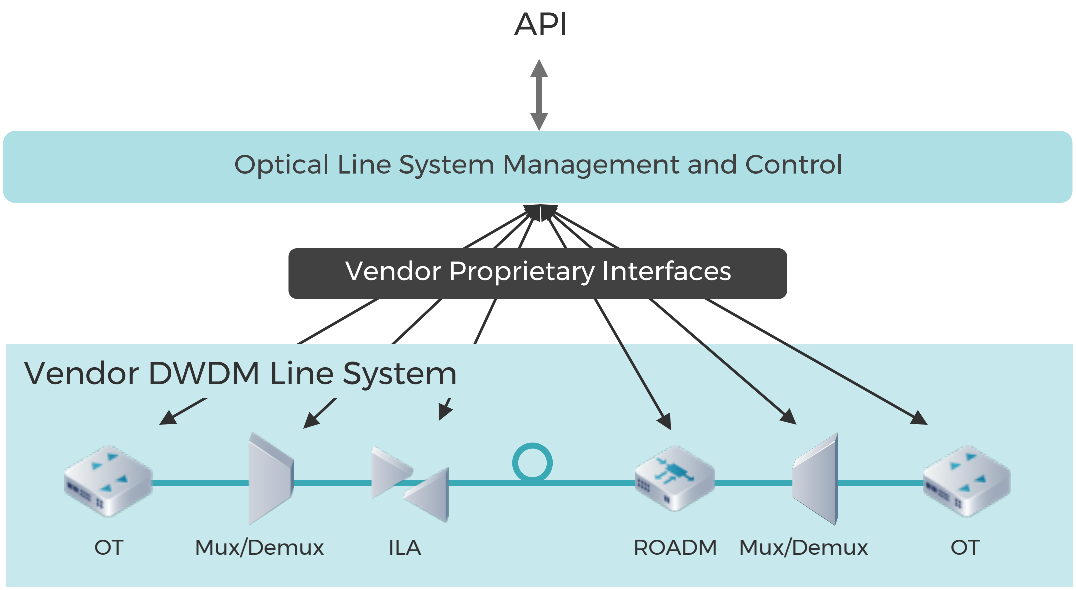
An additional driver for the disaggregated systems, is to develop a common ground for network planning and system design, which for the closed systems is very vendor dependent. The DWDM wavelength planning design logic is developed proprietary by each DWDM line system's vendor and therefore it is not available for the operators. Developing an open framework for the system design and impairment validation will give the operators much more visibility and understanding of their investments. To summarize, the areas of benefits introduced by Open Optical Networks are:

- Expand supply chain flexibility and foster competition.
- Mix and match O-OLIs over the same O-OLS.
- Decouple the lifecycle of closed optical systems network elements taking benefit, for example, of best technology for transponders/muxponders when available.
- Enable vendor's independent DWDM networks design and impairment validation to fully exploit network capacity avoiding vendor lock-in.

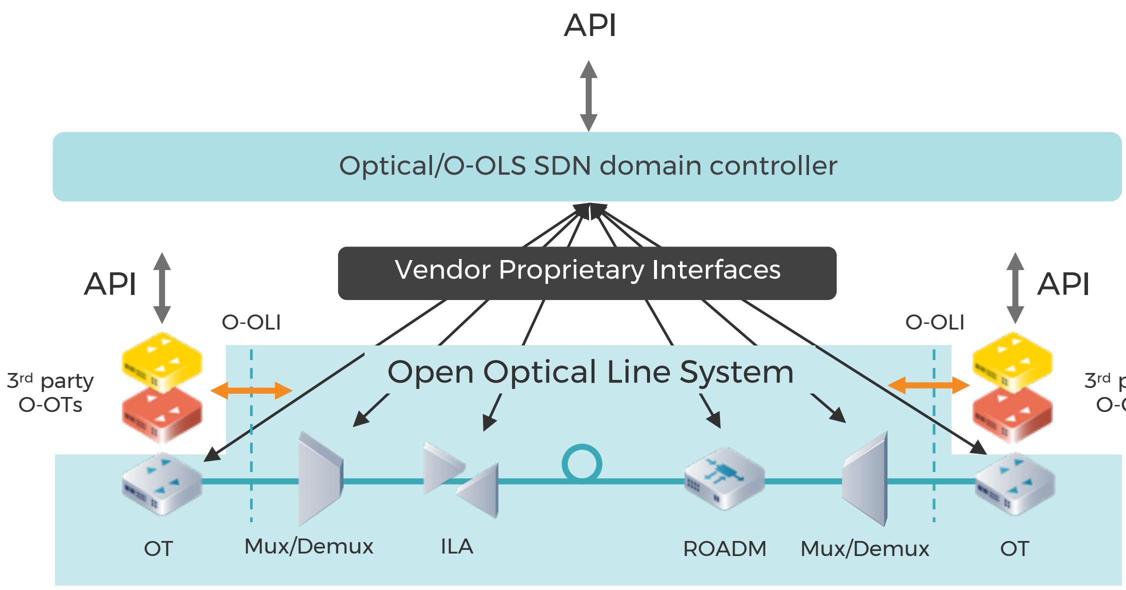
It should also be acknowledged that there are some challenges with disaggregated DWDM systems. We can anticipate a more complex procurement procedure for the operators, more responsibility concerning system integration, increased effort for testing and evaluation, a more complex life cycle and connection management in a multi-vendor environment.

2.2 Disaggregation

The evolution of optical networks towards SDN, with converged management and control and open/standard interfaces, makes possible the evolution from current single vendor monolithic/aggregated optical networks (Figure 2a) towards more open multi-vendor disaggregated optical networks.



a)



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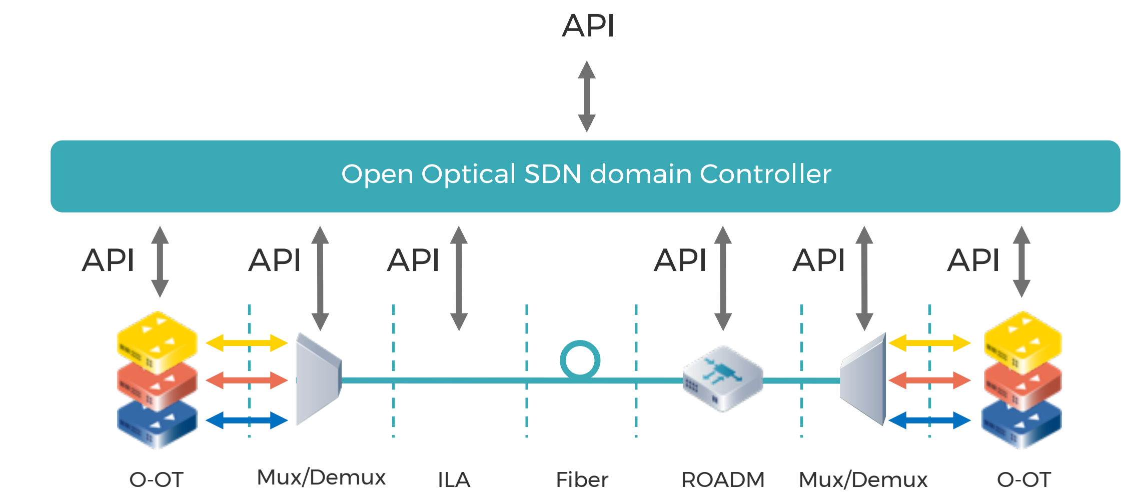

c)

Figure 2. a) Aggregated open transport network b) Partially disaggregated O-ON c) Fully disaggregated O-ON.

An open optical transport network can be partially disaggregated or fully disaggregated (Figure 2b and Figure 2c). The partially disaggregated architecture is divided into O-OTs and O-OLS segments. In the partially disaggregated architecture, the O-OLS has a single point of management, while in a fully disaggregated architecture, the SDN controller manages each individual network element including O-OTs and all the NEs belonging to an OLS, i.e., ILA, Mux/Demux and ROADM/FOADMS.

In the TIP OOPT target architecture, the OT building blocks are decoupled from the O-OLS, meaning they can be provided by different vendors and be managed independently. The Optical/O-OLS SDN domain controller is able to manage the 3rd party O-OTs from a resource discovery, provisioning, operation, fault and performance monitoring perspectives. This end-to-end manageability together with the network programmability through the optical SDN domain controller North Bound Interface (NBI), is a key part to achieving a higher degree of automation of the optical network, including IP and Optical multi-layer scenarios, when the hierarchical SDN controller is deployed.

Compared to a fully disaggregated system, the partially disaggregated system is expected to be less complex to manage, since one vendor is responsible for implementing the system integration of the O-OLS and providing a reliable solution. The organization that takes responsibility for the system integration of the fully disaggregated O-OLS, will have to ensure the system design, including the optical power management and integration testing.

The partial disaggregated architecture, described in this whitepaper, is the target architecture desired by the operators. It fulfils the required objectives by decoupling the lifecycles of O-OTs and O-OLS, allowing a flexible pay-as-you grow strategy for capacity deployment, non-constrained to a single vendor solution and permitting the desired goal for open network planning of optical channels.

A partially disaggregated optical network may consist of one O-OLS or multiple O-OLS domains; depending on this, the architectural requirements may vary. This whitepaper aims at defining the target framework for both single domain and multi-domain partially disaggregated optical networks.

The target scope for a partially disaggregated scenario is summarized by the following high-level statements:

a) Single domain O-OLS vendor segment management & control.

- Bookended O-OLIs over a single domain O-OLS.
- Interoperable O-OLIs over single domain O-OLS.

b) Multi-domain O-OLS vendor segments management & control.

- Bookended O-OLIs over a multi-domain O-OLS.
- Interoperable O-OLIs over multi-domain O-OLS.
- Single domain O-OLS management & control, where the O-OLS controller does not support 3rd party OTs integration.

For single domain scope, defined by a) statement and sub-statements, the description of the target high-level architecture is illustrated in Figure 3. In this scenario, the preferred solution, is that the Optical/O-OLS SDN Domain controller will be responsible of the full management of the partially disaggregated network domain, including the management of third-party O-OTs.

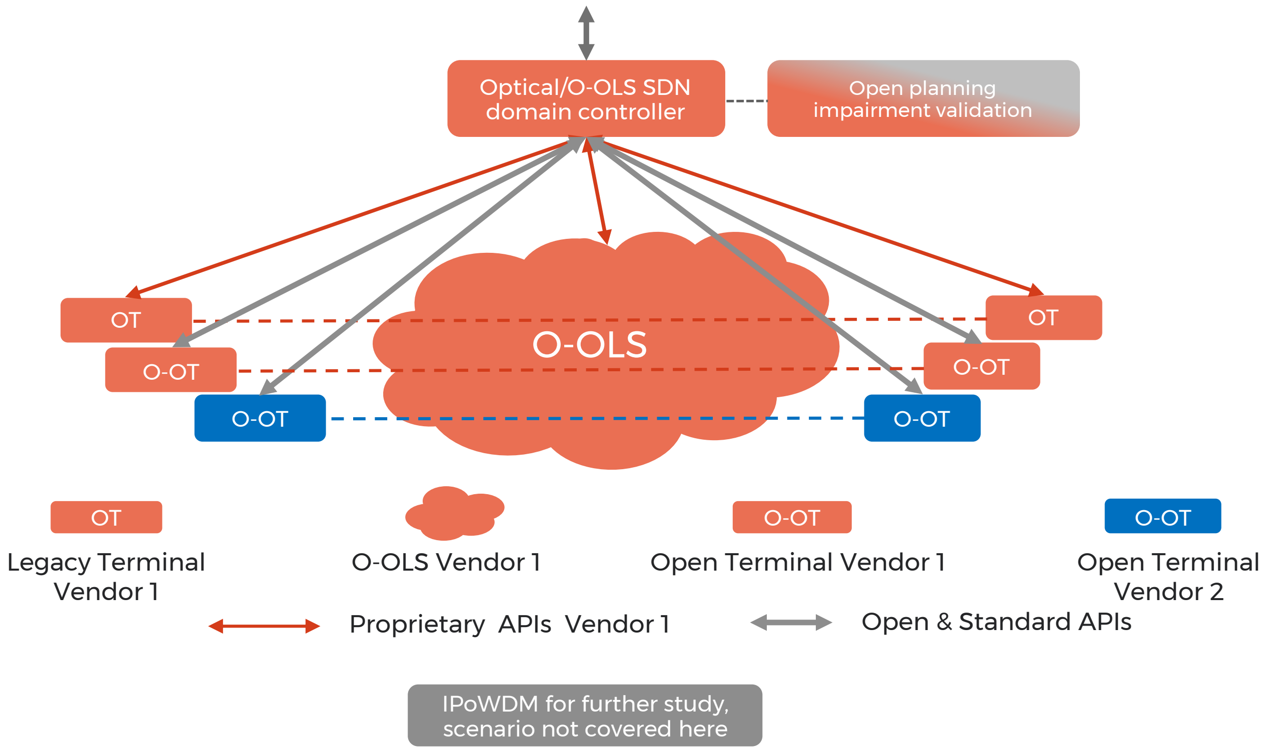

Figure 3. Partially disaggregated scenario : single domain

For multi-domain scope, defined by b) statement and sub-statements, the description of the target high-level architecture is illustrated in Figure 4.

The introduction of a Hierarchical SDN controller allows the management and control of multi-domain DWDM channels over several O-OLS domains. In some scenarios, this architecture can habilitate the disaggregation over a single O-OLS domain where the integration of 3rd party O-OTs is not supported by the O-OLS SDN Controller solution.

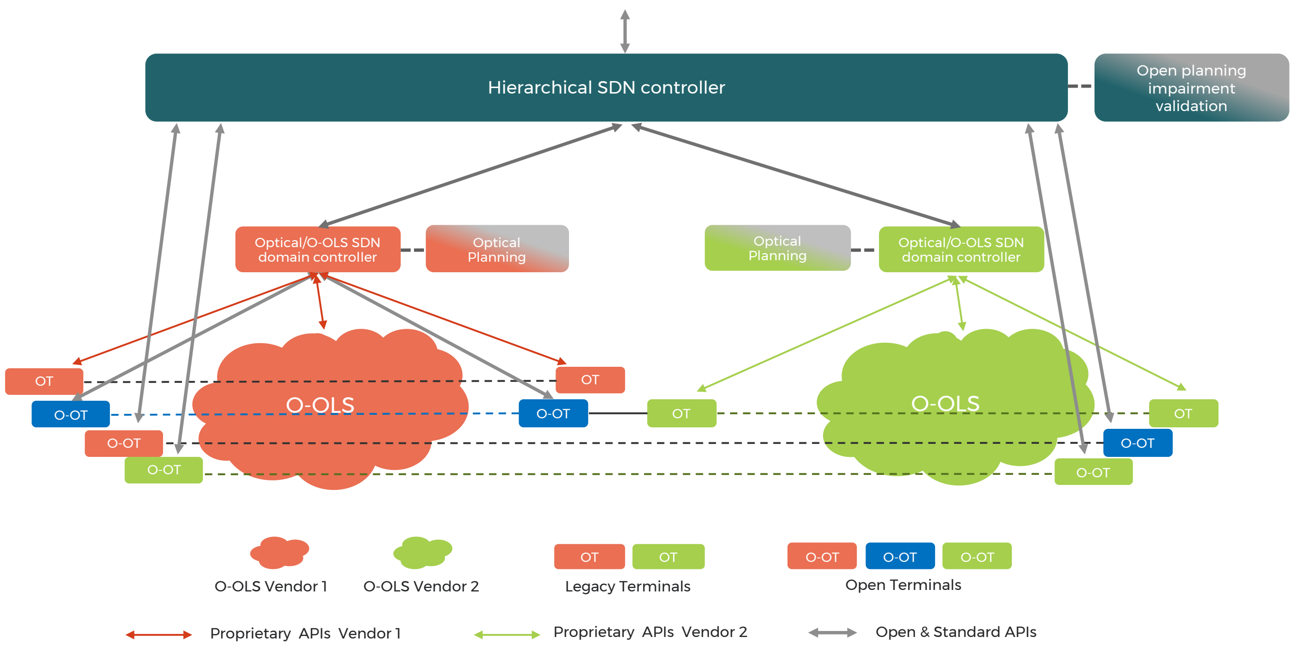

Figure 4. Partially disaggregated scenario - multi-domain

The SDN realization of the partially disaggregated optical network is discussed through the next sections and the proposed target SDN architecture is defined in detail in section 6.

2.3 Openness

The concept of O-ON enables a higher degree of freedom for the operators to select the type of open and disaggregated network elements that they need. The building blocks of the partially disaggregated O-ON should be open to provide access to optical planning, connection management and fault management. The openness of each building block is described in the sections 3, 4 and 5.

3

Open Optical Line Interfaces, O-OLI

The network elements that house the Optical Line Interfaces and provide the DWDM transport channels can be different types of O-OTs devices depending on the network element composition inside a hardware (HW) chassis such as:

- Standalone L1/L0 Optical Terminals (muxponder/transponder) with different levels of OTN switching capabilities.
- L2 packet-optical terminals and L3 routers with Optical Line Interfaces implementing IPoDWDM....

3 Open Optical Line interfaces, O-OLI

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- L2 packet-optical terminals and L3 routers with Optical Line Interfaces implementing IPoDWDM.

The minimum key requirements to consider any of these categories of NEs as an O-OT are:

- Open & Standard management interfaces (NBIs).
- Standalone deployment and management independent from the Open Optical Line System. Including:
  - Independent power supply.
  - Independent control and management.
- Optical Line Interfaces housing.
- Compliance with the O-OLI specification for the O-OLS.

The integrated management and control of L0 to L2/L3 (IPoDWDM) capabilities will be covered into a future OOPT whitepaper.

The scope of this white paper is to focus on partial disaggregation and O-OTs and not to further focus on additional disaggregation of the O-OT internal architecture. Independently of the disaggregation level of O-OTs architecture, the requirements for openness are the same.

The O-OLI is the missing counterpart for the O-OLS to realize a partially disaggregated transport network. The O-OLIs are the optical sources and sinks of the line side of transponders in traditional, aggregated networks and thus need to provide all the same data and control plane functionality as they do today (e.g. for provisioning, management, etc.). Work is on-going in specifying this interface in several fora including ITU-T [ITU-T

G.698.2] and OpenROADM W interface [OpenROADM]. In specifying O-OLI, MUST is looking carefully at the progress and the results obtained in these contexts.

3.1 Function

O-OLIs provide all the needed physical, control and management information to allow 'alien wavelengths' and possible OTN capabilities over the O-OLS like for aggregated line systems.

The O-OLIs can be divided into bookended, interoperable, and embedded line interfaces. Bookended line interfaces represent a connection between interfaces that have secured interoperability from one vendor. Interoperable interfaces represent a pair of line interfaces that can be from arbitrary vendors.

Embedded interfaces represent interfaces directly located into the O-OLS client equipment. For example, router and switches. The embedded interfaces can be bookended or interoperable, however, will not be further considered in this version.

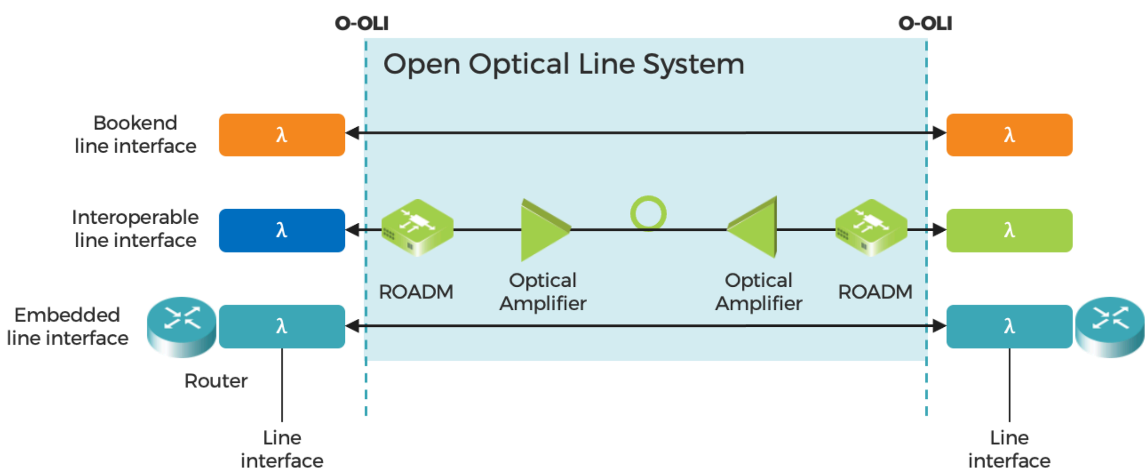

Figure 5. Open optical line interfaces.

3.2 Disaggregation and openness

This paper is restricted to describe the requirements and expectations of the minimum common part of an O-OT, the O-OLI. The O-OLI is housed within any O-OT and to illustrate that an example of an O-OT is provided in Figure 6. This example illustrates how an O-OT can be disaggregated into different functions; the O-OLI, the client side with pluggable optics, a NOS (Network Operating System) supported by generic install environment boot loader (ONIE), API and TAI (transponder abstraction interface) [TAI] connecting the transponder applications to the HW.

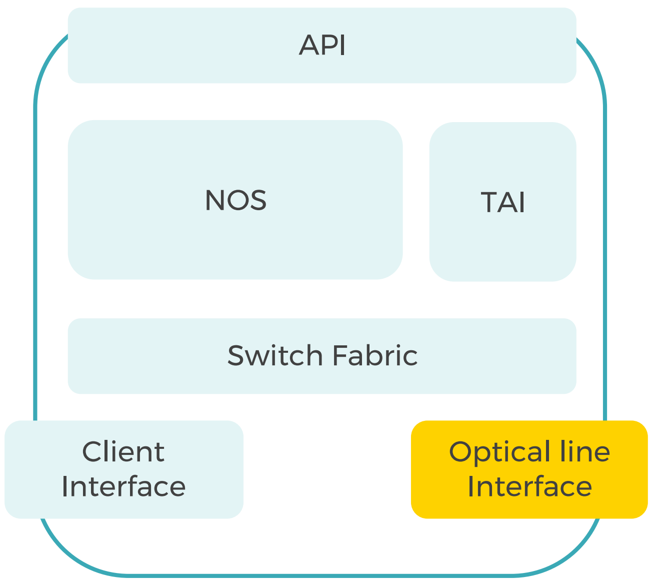

Figure 6. An example of a disaggregated Open Optical Terminal.

The O-OT should be open in the sense that it provides provisioning, management, and configuration capabilities of the O-OLI, such as power levels control, line transmission full characterization (operational modes, frequency setting capabilities) and fault management (FCAPS), including performance metrics like OSNR. All necessary data for impairment validation and optical path planning e.g., for Gaussian Noise Model in Python (GNPy) to be shared is described and included in section 5. All these management capabilities should be provided and be accessible via open standardized APIs towards SDN controllers [MUST Optical SBI TRD].

4

Open Optical Line System, O-OLS

The Open Optical Line System (O-OLS) in the target architecture supports coherent transmission, flexgrid ROADM and autonomous control of optical power levels. The total power levels and the individual power levels of media channels should be defined independently of equipment vendor where the wavelengths originate and be autonomously managed throughout the system...

4 Open Optical Line System, O-OLS

4.1 Function

The Open Optical Line System (O-OLS) in the target architecture supports coherent transmission, flexgrid ROADM and autonomous control of optical power levels. The total power levels and the individual power levels of media channels should be defined independently of equipment vendor where the wavelengths originate and be autonomously managed throughout the system. Any additional components required for this functionality are considered part of the O-OLS solution.

To complement the autonomous power control requirement description, it is expected that individual input signal power levels can be autonomously adjusted by the O-OLS, according to the optimal DWDM system transmission (taking other existing channels into account) and O-OLS power limitations.

The O-OLS should support inter-domain transparent media channel delivery. This functionality needs to be developed further with a detailed specification of the inter-OLS interfaces.

4.2 Disaggregation

The target solution is a partially disaggregated optical transport network as explained in Section 2. The O-OLS is abstracted via the Optical/O-OLS SDN domain controller NBI and therefore the hierarchical controller does not need to communicate with each network element within the OLS, i.e., ILA, Mux/Demux and ROADMs. The O-OLS should have border O-OLIs to accept external OTs (Figure 7).

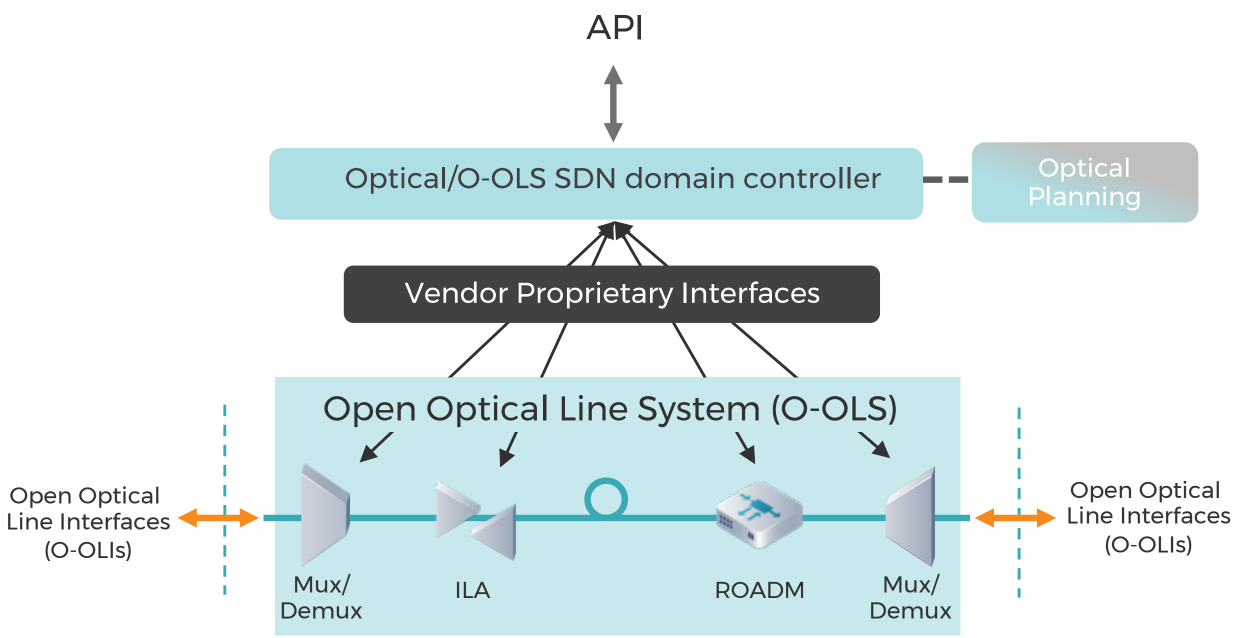

Figure 7. Components of the partially disaggregated O-OLS.

4.3 Openness

The partially disaggregated O-OLS should be open in different ways. It should provide transparent optical channels for the transport of third party DWDM signals ("alien wavelengths"); media channels [ITU G.872] of variable widths based on spectral grid according to [ITU G.694.1]. The optical media channels should be open/agnostic for arbitrary signal formats and spectral shapes such as single Media Channels and Media Channel Groups. Standardized O-OLI is to be specified for this purpose.

The O-OLS is also open in the sense that it supports O-OLS Controller NBI APIs for management of FCAPS (fault, line configuration, accounting, performance and security). All these management capabilities must be exposed through the NBI to external applications and the Hierarchical SDN Controller, to fulfil at least the following use cases:

- Diagnosis and health assurance through power level monitoring.

- Routing, spectrum assignment, impairment validation, modulation format assignment.
- Exposure of the complete topology and device inventory.
- Media channel service management.

Another important part of the openness is that the O-OLS vendor shares data required for third party impairment validation according to section 5.

5

Open Planning and impairment validation, O-PaIV

A planning functionality provides (1) OLS network design and (2) verification of EoL margins for connections (wavelengths) between optical line interfaces. In an open environment any party can perform (1) and (2) since necessary data is shared by the O-OLS and the O-OLI vendors...

5 Open Planning and impairment validation, O-PaIV

5.1 Function

A planning functionality provides (1) OLS network design and (2) verification of EoL margins for connections (wavelengths) between optical line interfaces. In an open environment any party can perform (1) and (2) since necessary data is shared by the O-OLS and the O-OLI vendors. All data related to devices must be shared by the O-OLS and the O-OTs. Data related to fiber and external physical plant (ODFs, distances) must be provided by an external data base in case the information is not present in the controller. The impairment validation is carried out online, which means that the domain controller provides data associated with the O-OLS and O-OLI vendors via the SDN hierarchy.
In a single domain scenario, the planning and impairment validation can be carried out by a vendor-specific planning function implemented in the O-OLS domain controller.

In a multi-domain optical scenario, although different approaches are possible, the planning and impairment validation application could be left entirely to the top level hierarchical Optical SDN controller to have the full view of the optical network, meaning all O-OLS systems and O-OLIs, as represented by
Figure 8. By having the full view of the optical network, intra O-OLS domain and inter-domain optical connections (wavelengths) are possible to validate and optimal inter-domain path computation is possible.

The O-OLS and O-OLI should expose relevant data to a path computation engine (PCE), or similar function to assure planning, routing, explicit routing, and impairment validation. The topology with its links and nodes, deployed services and spectrum availability should be shared via the Hierarchical optical domain controller.
The inventory data for fiber plan should be consolidated through the same data model in the north bound interface of the Hierarchical optical SDN controller.

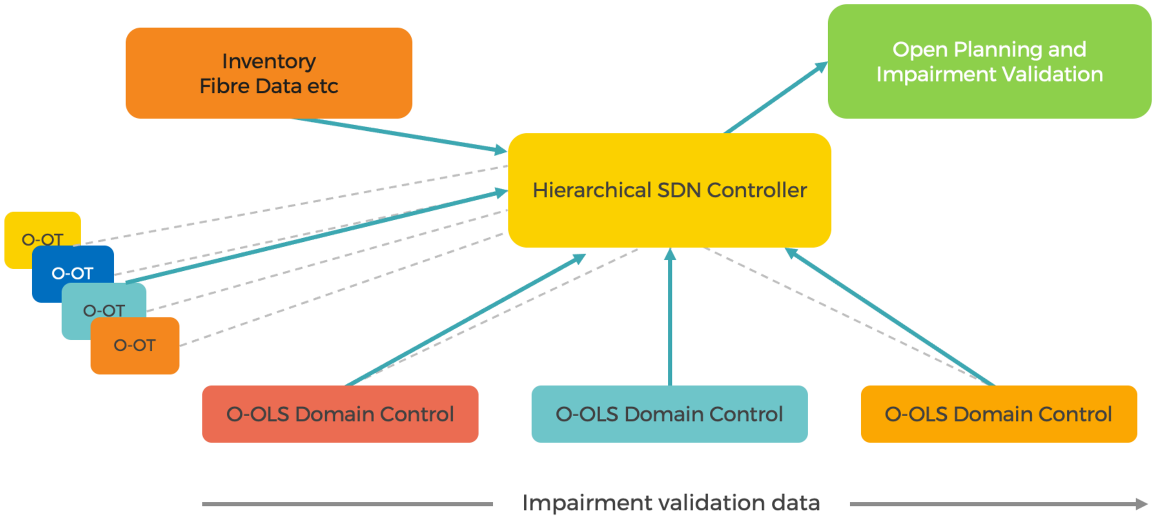

Figure 8. SDN controllers and data flow for multi-domain impairment validation.

The O-OLS and the O-OLIs contribute to the impairment validation with both static and dynamic data, for example, amplifier gain, noise figures, span losses and power levels at all points in the system. The SDN hierarchy provides connectivity to network elements and support systems and the data that characterizes the network should be available online even though it is static.

Having the data online for planning and impairment validation, enables learning session for Machine Learning (ML) and improves reliability in QoT estimation with less manual intervention.

Embedded OTDR is preferably used to report fiber lengths, fiber losses, splice losses, and connector losses to have a detailed and accurate view of the O-OLS attenuations.
For planning, routing and impairment validation, the following data should be shared by the O-OLS vendors. This data should be provided online, meaning that the data is stored locally in the network devices or domain controllers, to be consumed by an external online planning tool.

- The equipment library:

  - Name and specifications (e.g. amplifiers NF and min-max-gain), in a standard way (e.g. GNPy template [GNPy LIBRARY]).
- The topology of the network to be analysed:
  - Topology.
  - Equipment settings (i.e., gain, power settings for amplifiers, output power into spans, total and for the nominal channel).
  - Fibre attenuation.
  - ROADM impairments for add/drop paths and internal connectivity matrix and inventory. For example, an amplifier is needed for add/drop, intermediate stages. Equalization rules, and target per channel powers for the nominal case.

    An exhaustive list of needed parameters is described in the IETF draft optical impairment topology [IETF CCAMP OPTICAL].
- The deployed channels:
  - Routing and spectrum information, as well as attached O-OLIs configurations.

For planning, routing and impairment validation, the following data should be shared by the O-OT/O-OLIs vendors:

- Transceivers list of supported modes,
- For each mode, its capability:
  - mode identifier and eventually organizational mode/ model/ software versions, modulation, FEC-type for compatibility checking.
  - baudrate, roll-off, min required OSNR at receiver side in 0.1 nm bandwidth @nominal optical power on receiver, min q-factor, generated OSNR at emitter side, max acceptable chromatic and polarization mode dispersion on receiver and eventually associated penalties, for feasibility checking.
  - bitrate, frequency range, per channel input optical power acceptable range, max total power accepted on receiver, output optical power range, minimum required spectrum occupation, for compatibility with ROADM and spectrum assignment checking.

If the O-OLI support an open control interface, the information should be available via this interface. An initial openconfig extension proposal is included in Annex A - Operational Mode augment of [MUST Optical SBI TRD].

The part that manages the fiber plant should provide the fibre types, fibre length, loss coefficients of the fiber, number of connectors and splice distribution. The goal is that this information is shared between the external inventory and the SDN Controllers through Open & Standard interfaces.

5.2 Disaggregation

Even though the target architecture is partially disaggregated, the planning and impairment validation function requires full open data visibility of the optical systems network elements, amplifiers, ROADMs and the optical line interfaces towards the open optical hierarchical SDN controller and the attached entities e.g. for PCE.

5.3 Openness

This whitepaper is defining guidelines for Open Planning and Impairment Validation applications (O-PaIV). The applications support planning of multi-vendor networks based on listed data in section 0. For both the single domain and multi-domain scenarios, planning and impairment validation can be carried out for O-OLIs. The O-PaIV is open in the sense that it supports open API and provides a definition of the data that is required to execute the planning and impairment validation.

Disaggregated impairment validation function requires non abstracted open data visibility of the O-OLS NEs and the O-OLIs as described in section 5.1.

As a good example of O-PaIV, TIP OOPT are developing the GNPy that is a vendor independent open-source application for verification of EoL margins of optical connections. The GNPy requires a defined input that can serve as a reference for data to be provided to open optical planning application.

6

Management, SDN and API

The purpose of this section is to define the TIP OOPT MUST's reference architecture for management, SDN and APIs of Open Optical Networks implementing the partial disaggregation guidelines introduced in this whitepaper. This architecture is deeply aligned with the Open Transport SDN Architecture defined…

6 Management, SDN and API

The purpose of this section is to define the TIP OOPT MUST's reference architecture for management, SDN and APIs of Open Optical Networks implementing the partial disaggregation guidelines introduced in this whitepaper. This architecture is deeply aligned with the Open Transport SDN Architecture defined in the foundational MUST program whitepaper [MUST ARCH]. In Figure 9 it is shown the MUST program's architecture focused on its realization in the Open Optical Networks (O-ONs) domain.

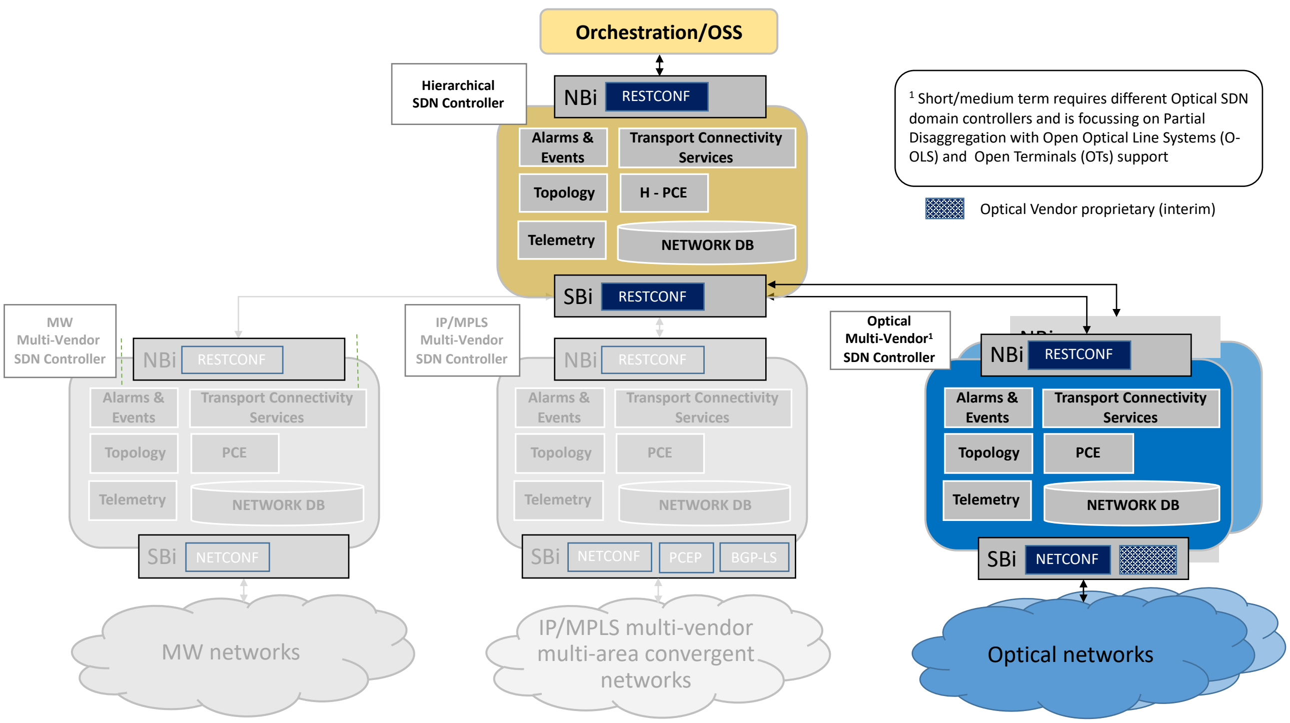

Figure 9. TIP MUST SDN architecture for Open Optical Networks.

Software Defined Networking (SDN) principles are a central requirement in the proposed architecture due to the need to standardize the different control and management interfaces between SDN controllers and optical devices. Standardization is a key requirement to enable the desired openness and disaggregation concepts by introducing interoperability at the data plane and control/management levels in O-ONs.

Moreover, it enhances the management in the optical domain by improving resource inventory, visualization, programmability, planning and network design in multi-vendor environments.

Three basic requirements are key to realising a partially disaggregated network solution from the control and management perspective:

1) The O-OLS must allow transporting third-party DWDM channels over its HW. For this purpose, media channels management must be allowed within the O-OLS.
2) The introduction of an Optical/O-OLS SDN domain controller for the network control and management of each OLS domain which exposes full management and control through an Open & Standard Northbound Interface (NBI).
3) The support of Open & Standard interface by the OTs, consistent with the Southbound Interfaces (SBI) allowed by the Optical/O-OLS SDN domain controller and/or the Hierarchical SDN Controller.

The MUST program has released the first version of the Technical Requirements Documents (TRD) which defines the target implementation of the Optical SBI [MUST Optical SBI TRD] and NBI [MUST Optical NBI TRD] for the Optical/O-OLS SDN domain controller, including into its scope, the partially disaggregated network requirements and use cases. These TRDs include the transport protocols and information models which conform these interfaces [MUST ARCH].

In a disaggregated architecture, the management capabilities of the optical SDN domain controller differ depending on the underlying architecture.
As explained in section 0, two architectures need to be considered when defining MUST requirements for management, SDN and APIs: single domain partially disaggregated architecture and multi-domain partially disaggregated architecture.

6.1 Single domain partially disaggregated

For single domain scope the preferred architecture to realize the partial disaggregation includes the management of third-party O-OTs by the vendor proprietary O-OLS controller. The detailed description is illustrated in Figure 10. If for any reason this solution is unfeasible, please refer to the multi-domain partially disaggregated architecture restricted to the simpler case of a single domain.

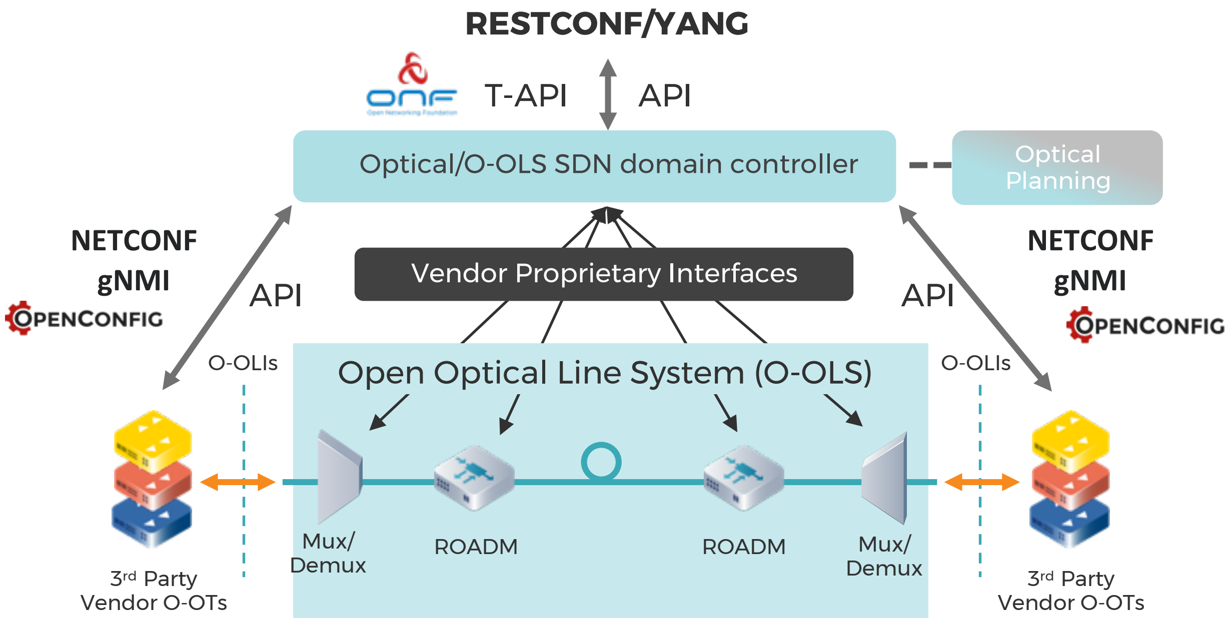

Figure 10. Single domain partially disaggregated architecture with single Optical SDN domain controller

In this architecture, the O-OLS vendor's management system (referred as Optical/O-OLS SDN domain controller) supports the management and control of third-party O-OTs through open and standard SBI in addition to the management of the O-OLS own vendor network elements (ILAs, ROADMs, own Terminals). In this case, the set of technical requirements which defines the architecture are:

- Open & Standard O-OLS Controller NBI.
- Vendor agnostic O-OT abstraction through the Open & Standard O-OLS Controller NBI.
- OT 3rd party vendor integration through Open & Standard O-OLS Controller SBI and OT device NBI.
- O-OLS exposes open data for planning and impairment validation through Open & Standard NBIs.
- Online planning and impairment validation of all DWDM circuits including those originated from 3rd party OTs, either from a proprietary or third-party vendor solution.

- Vendor agnostic O-PaIV for single domain DWDM channels:
    - Bookended O-OLIs over a single domain O-OLS.
    - Interoperable O-OLIs over single domain O-OLS.

This scenario is considered mature in terms of the status of its required open and standard interfaces. Optical/O-OLS SDN domain controller SBI interface is fully described in [MUST Optical SBI TRD] and should support both NETCONF and gNMI with OpenConfig data models, while [MUST Optical NBI TRD] covers an initial set of use cases and the selected data models (ONF T-API) and protocols (RESTCONF) for the NBI of Optical/O-OLS SDN domain controller.

The subsequent versions of the [MUST Optical NBI TRD] interface will define all data models and APIs required for routing, wavelength and spectrum assignment and impairment validation. Online planning tool, as shown in picture above can be either from the same Optical/O-OLS SDN controller vendor or from a 3rd party vendor or an open-source planning tool (e.g., GNPy) as described in section 0.

The MUST working group will also define the API between the Optical/O-OLS SDN domain controller and the on-line PaIV tool.

6.2 Multi-domain partially disaggregated architecture

For multi-domain scope the partial disaggregation recommended architecture introduces the Hierarchical SDN controller as described in
Figure 11:

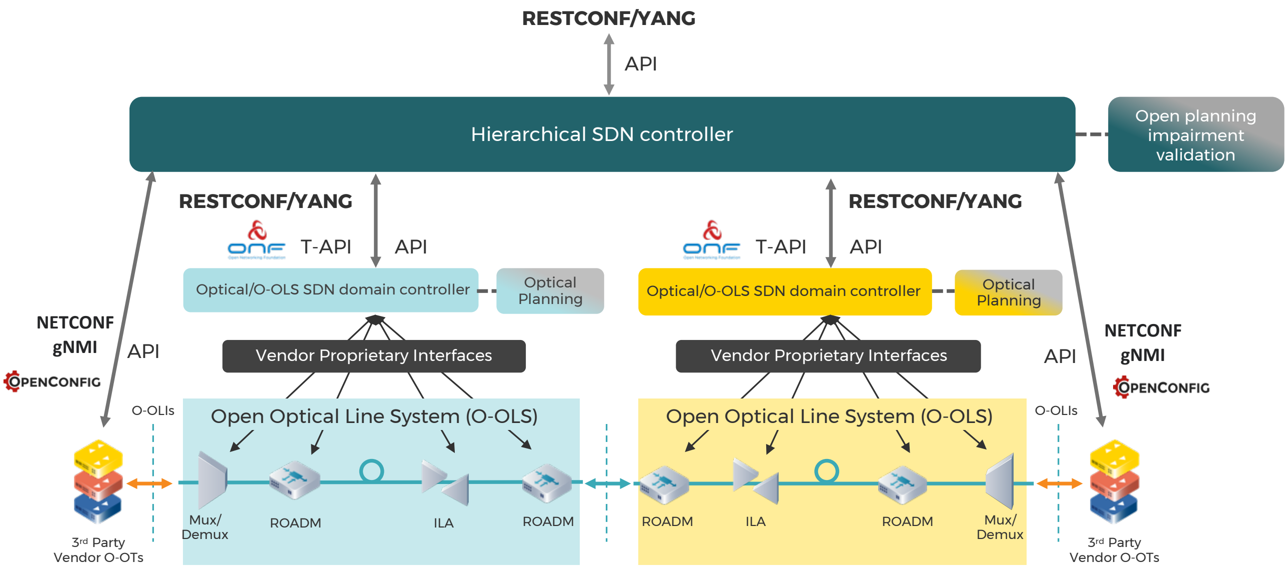

Figure 11. Partially disaggregated optical network based on hierarchical SDN architecture.

This architecture introduces a Hierarchical SDN Controller (H-SDN) in the network for the management of the OTs deployed over different O-OLSs in a multi-domain scenario but is suitable also for the single domain scenario where the solution described in the previous chapter is not applicable. In this architecture, the Hierarchical SDN controller is the only entity able to have the end-to-end view and therefore has the responsibility to perform the full control/management of the O-OTs to support the partially disaggregated scenario.

Similarly, to the single domain partially disaggregated scenario, the Hierarchical SDN controller must support the standard SDN domain controller SBI with the OT's and the SBI with Optical/O-OLS SDN controller for each domain.

The complete set of feature requirements which defines this architecture is the following:

- Hierarchical SDN Controller to support Open & (Standard) SBI interfaces (MUST D1, D2) for managing:
    - 3rd party vendor OTs.

  - The multi-domain O-OLS vendor segments.
  - The single domain O-OLS when the O-OLS SDN controller does not support 3rd party OTs integration yet.

- Open & Standard O-OLS Controller NBI.
- Open & Standard H-SDN Controller NBI.
- OT 3rd party vendor integration into H-SDN Controller and/or O-OLS Controllers, through Open & Standard O-OLS Controller SBI and OT device NBI.
- Vendor agnostic OT abstraction through Open and Standard O-OLS controller NBI.
- Vendor agnostic O-PaIV for single domain and multi-domain DWDM channels:
  - Bookended O-OLIs over a single domain O-OLS.
  - Bookended O-OLIs over a multi-domain O-OLS.
  - Interoperable O-OLIs over single domain O-OLS.
  - Interoperable O-OLIs over multi-domain O-OLS.

- O-OLS Controller exposes open data for optical planning and impairment validation through Open & Standard NBIs.
- Standard O-OLI transmission formats (400ZR/OpenZR+/400ZR+).

As already described earlier in this section, the SBI interfaces with OTs are NETCONF and gNMI as described in [MUST Optical SBI TRD]. While the NBI interface of each Optical/O-OLS SDN controller is defined in [MUST Optical NBI TRD].

T-API and OpenConfig data models were selected by MUST operators as first target implementation for NBI and SBI respectively, due to wider vendor support today. Other current standard data models such IETF ACTN and OpenROADM can be considered in the future. We encourage ONF T-API and IETF ACTN, also, OpenConfig and OpenROADM, to start converging into a unified model definition.

The MUST working group will also define the API between the Hierarchical SDN domain controller and the online PaIV tool.

Note that the architecture shown in
Figure 11 may also apply to single domain partially disaggregated scenario when the Optical/O-OLS SDN Domain Controller is not able to manage O-OTs from 3rd party

vendors. Then the only entity capable of managing and controlling those O-OTs may be the Hierarchical SDN controller. Line System management and control solutions should at least support the standard NBI interface as described previously in this section.

7

Conclusions and Next Steps

The primary goal of this whitepaper is to accelerate the adoption of the common architecture and standard interfaces for the realization of the Open Optical Network concept described extensively in this whitepaper.

7 Conclusions and Next steps

The primary goal of this whitepaper is to accelerate the adoption of the common architecture and standard interfaces for the realization of the Open Optical Network concept described extensively in this whitepaper.

This whitepaper includes a unified consensual view, among the operators involved, of the target architecture and requirements to realize an Open Optical Network through the partial disaggregation strategy. The paper identifies the basic components of this proposed architecture and describes in detail the requirements of each building block, as well of the SDN open and standard interfaces between them.

The operators signing this document acknowledge the importance of a common and unified validation process to realize the open optical networking ambitions expressed here.

There are some open points which need to be further studied, analyzed, and developed by the TIP OOPT MUST subgroup together with relevant players in the industry, including but not limited to:

- IPoDWDM integration in the partially disaggregated architecture.
- Full detailed definition of requirements for O-OLS inter-domain interfaces to realize multi-domain transparent services.
- Full development of APIs for O-PaIV use cases.

8

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8 References

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9

Acronyms

9 Acronyms

API	Application Programming Interface
CANDI	Converged Architectures for Network Disaggregation & Integration (TIP)
DCI	Data Centre Interconnect
DCN	Data Communication Network
DOS	Disaggregated Optical Systems (TIP)
DWDM	Dense Wavelength Division Multiplexing
FOADM	Fixed Optical Add/Drop Multiplexer
gNMI	gRPC Network Management Interface
GNPy	Gaussian Noise Model in Python (TIP)
gRPC	Remote Procedure Call
H-SDN Controller	Hierarchical SDN Controller
ML	Machine Learning
MUST	Mandatory Use Case Requirements for SDN For Transport (TIP)
NBI	North Bound Interface
ODF	Optical Distribution Field
OLS	Optical Line Systems
ONF	Open Networking Forum
ONIE	Open Network Install Environment
O-OLI	Open Optical Line Interfaces
O-OLS	Open Optical Line Systems
O-ON	Open Optical Networks
OOPT	Open Optical Packet Transport (TIP)
O-OT	Open Optical Terminal
O-PaIV	Open Planning and Impairment Validation
OT	Open Terminal
OTN	Optical Transport Network
PCE	Path Computation Engine
PSE	Physical Simulation Environment (TIP)
ROADM	Reconfigurable Optical Add/Drop Multiplexer
SBI	South Bound Interface
SDN	Software-Defined Networking
TAI	Transponder Abstraction Interface (TIP)
TAPI	Transport API (ONF)
TRD	Technical Requirements Document

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