CTTC

Advances in SDN control for Beyond 100G disaggregated optical networks

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TeraFlow

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Abstract – Goals and Non-Goals

This tutorial considers the evolution of SDN control for optical transport networks in disaggregated scenarios, focusing on its requirements and challenges when applied to "beyond 100G" networks -- term that jointly refers to the use of coherent technology, data rates beyond 100G and the evolution of OTN standards to support rates such as 200G, 400G, or 800G --.

The tutorial will cover use-case driven SDN development, new challenges and requirements such as the need to account for physical impairments, multiband / SDM control, improved fault/alarm management, network sharing or optical telemetry and streaming.

Goals

An overview of architectures, emerging use cases, trends, challenges and status (*advances*) of the applicability of the *SDN* paradigm(s)

- To the control, management and monitoring (*operation*) of optical networks (*focusing on the photonic media layer*),
- To support ever increasing data rates (*B100G*) in specific scenarios (*[partial] disaggregation*).
- Along with related recent developments, work items, open questions,
- Where selected (and simplified) data models are used for illustrative purposes (and are industry relevant)

Non-Goals

- A tutorial on Yang / YAML / Protobuf or NETCONF / RESTCONF / gRPC / gNMI /…
  - [1] R. Casellas et al., "Control, Management, and Orchestration of Optical Networks: Evolution, Trends, and Challenges," J. Lightwave Technol. 36, 1390-1402 (2018)
  - [2] R. Vilalta et al., “Experimental evaluation of control and monitoring protocols for optical SDN networks and equipment” JOCN, Vol. 13, No. 8, pp. D1-D12, August 2021.
- An in-depth or exhaustive presentation of device, service, or network data models

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Tutorial Outline

- Background, Definitions and Scope
  - SDN: model driven development, configuration and control, alarms & notifications
  - What is Disaggregation /Disaggregation models? Interest of Partial Disaggregation, What is B100G?
- Reference architecture(s)
  - Hierarchical Multi-domain Partially disaggregated networks
  - Open Optical Terminals (O-OT) and TAPI enabled Open Optical Line System (O-OLS) controllers
- Challenges and New Requirements: Increased flexibility ←→ Increased complexity
  - Use case driven SDN development: Drive the development of data models, implementation and validation
  - QoT, physical impairment validation, external planning and computation tools.
  - Increasing Capacity: Multiband, SDM control
  - Improved Fault Management / Alarm frameworks, TCA, Performance monitoring
- Infrastructure Sharing and Network Virtualization
  - Sharing Open-Optical Line Systems and “Spectrum Services”
- Telemetry and Streaming
  - Efficient, High-volume data telemetry, monitoring.
- Conclusions

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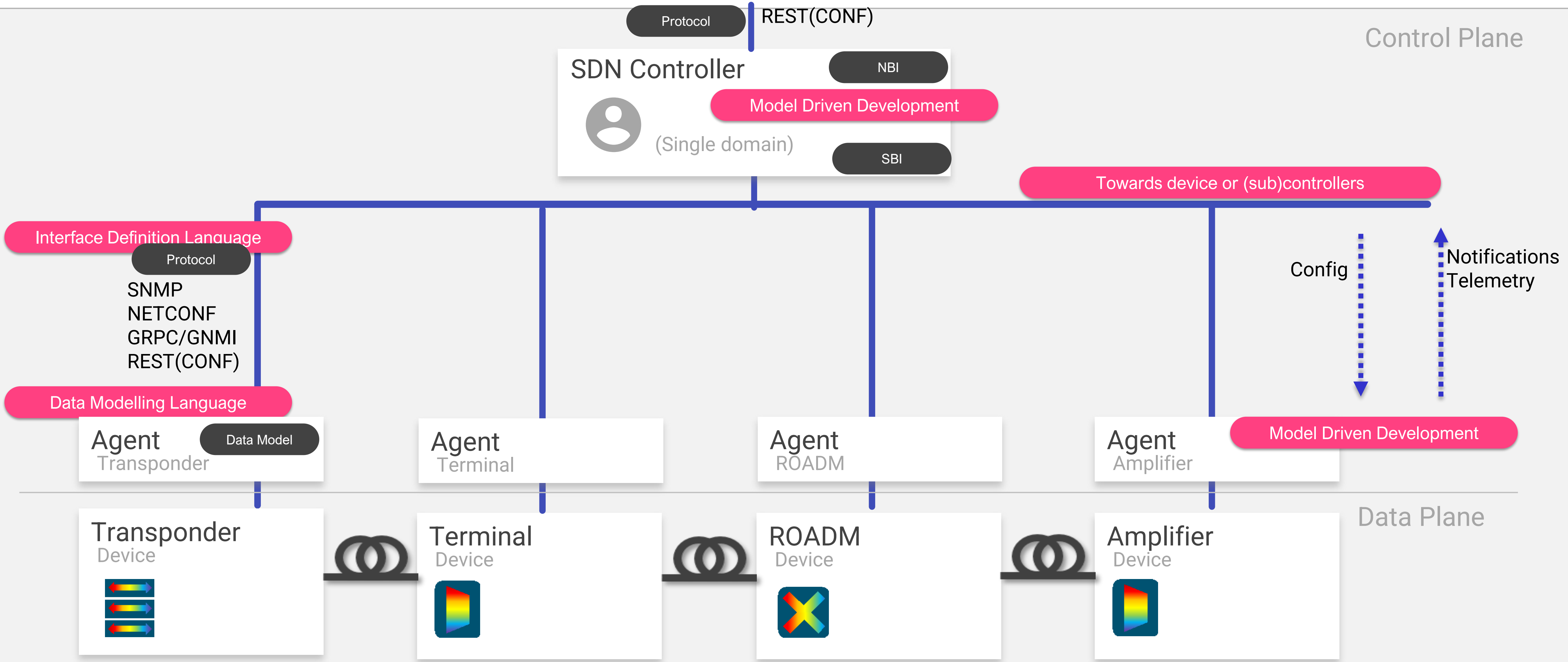
A simplified view of SDN control of Optical networks



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(Data) Model Driven Development, Control and Monitoring

- An approach to design (**distributed**) systems…
  - Control/Management/Monitoring/Operation of Optical Networks
  - Direct application to SDN and Streaming Telemetry
- Based on the systematic use of **data models…**
  - For modeling services, control plane & management constructs (topologies, connections), devices…
- Which can be **automatically** processed, validated, …
  - Using advanced software tools
  - Avoiding error-prone and repetitive/low level tasks
- Used within optimized **transport protocols**
  - Such as NETCONF, RESTCONF or HTTP2/gRPC/gNMI…
  - For aspects related to remote control and monitoring
- So, **business logic and applications** can be developed
  - Enabling Network Programmability and Automation
  - Focusing on the actual use cases and problem-solving

PILLARS

Functional Architecture(s)
For configuration and monitoring

A transport protocol
How to access and modify data?

Open/Standard Data Models
Describing Systems and Devices

Data Modelling Language
To define such data models

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What is a Data Model?

Data Model

How to structure and define data?

"Representation of a system in terms of objects & entities, roles, relationships, cardinalities, constraints."

Benefits?

Non-ambiguous specification

Enhance the understanding of the system, convey structure of data and underlying semantics. Reference (self-documentation)

In practice

How-to use?

Portable File using a Data Modelling Language, versioned and integrated in a toolchain.

```
module cttc-tv {
  namespace "http://www.cttc.es/ctv";
  prefix ctv;
  organization "CTTC";
  contact "ramon.casellas@cttc.es";
  description "TV Yang model";
  revision "2018-01-30" {
    reference "0.1";
  }
  typedef volume-type {
    type int32 {
      range "0..100";
    }
  }

  container info {
    config false;
    leaf vendor {
      type string;
    }
    leaf serial {
      type string;
    }
  }
```

```
...
container parameters {
    config true;
    leaf input {
      type enumeration {
        enum hdmi1;
        enum hdmi2;
      }
    }
    leaf volume {
      type volume-type;
    }
    leaf channel {
      type uint32 {
        range "1..512";
      }
    }
  }
```

```
...
rpc reboot {
    input {
      leaf delay {
        type uint16;
      }
    }
    output {
      leaf status {
        type empty;
      }
    }
  }


  notification sleep {
    leaf delay {
      type uint16;
    }
  }
}
```

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What do we want in MDL / IDL?

Macroscopic

Flexible Data Modeling
Config, Operational & Notifications

Ease of Use
“Must” for adoption

Industry Coordination
Adoption and use

Readability?
vs Parsing Complexity,..

Features

Clear specification
MSA, SDOs, OSS...

Modularity, Composability
Augment/Inherit, Reuse, Choice,...

Modern Features
Type Systems, Relationships, ...

Open/Standard Data Models
Describing Systems and Devices

Development

Toolchain Availability
Prototyping, Robust solutions

Language Support
Bindings, stub generation

Reference Implementations
OSS / Libraries

MDL: Model Definition Language

IDL: Interface Definition Language

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What do we want in a Protocol Architecture to access data?

Macroscopic

Support CRUD operations
Config, Operational & Notifications

Low Overhead, Latency
Latency critical environments

Security
Credential Management, …

Industry Coordination
Adoption and use

Modern Features

Efficient encodings
Binary vs Text, Compression, ..

Pipelining, Multiplexing
Async support, Server push…

Modern "SDN"

- Advanced flow control
- Transactional semantics
- Scalability,
- Support for "Message Buses"
- Sequential consistency
- Synchronization primitives
- Rollback capabilities
- Support for multiple datastores…

Development

Toolchain Availability
Prototyping, Robust solutions

Language Support
Bindings, stub generation

Reference Implementations
OSS / Libraries

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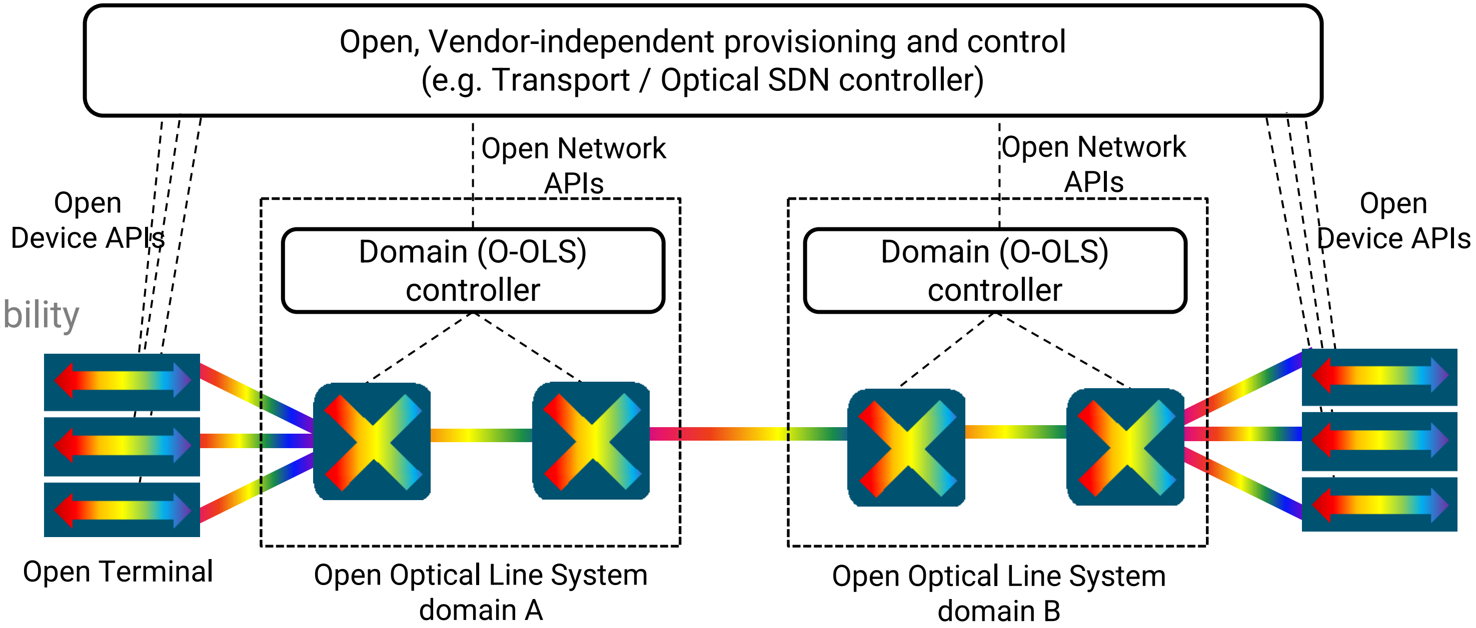
Optical Disaggregation

- Optical Disaggregation
  - Flexible Composition of network elements (Hw & Sw)
  - Modular network element architecture; Interoperability through standard interfaces
- Full (component – level) disaggregation
  - The transport system is disaggregated,
  - Optical network elements (e.g., ROADMs) can be provided by different vendors.
- Partial Disaggregation
  - Optical Terminals (OTs) and Open Optical Line Systems OLS can be supplied by different vendors.
  - OT lifecycle is shorter than the OLS' (e.g., coherent innovation)
  - OT represent most of the cost of the WDM network.



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What is Beyond 100G? - Different meanings wrt context

- The adoption of “OTN 3.0” with the definition of OTU-Cn interfaces
- The alignment with client rates e.g., IEEE 200GE, 400GE,…
- The use of “advanced optical technologies”
  - Systematic use of coherent transmission such as Polarization Multiplexed Phase Modulation (PM-16QAM)
  - The adoption of silicon photonics
  - Advanced FEC algorithms and pre-compensation
  - High speed ADC and complex DSP
- Increasing Capacity Requirements and data rates 200G, 400G, 800G,…
  - Multiple degrees of freedom and switching – New Layering / new constraints
  - Single-Carrier X00G o “Super channels” OTSi with Subcarrier / OTSiA
  - Multi-band switching; SDM switching

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OTN 3.0 - Question 11 of Study Group 15 (Q11/15)

- Extend OTN for rates beyond 100 Gbit/s and support new signals such as 400GE efficiently
  - First phase with G.709-2016 - Introduction of OTUCn and FlexO
  - Flexibility in FEC: different uses have different requirements
- ODUCn/OTUCn
  - OTUCn defined as an n × 100Gbit/s modular structure.
    - Highest OTUk was OTU4.
    - Allows for 200G, 400G, 600G or higher rate
  - Signal is only carried point-to-point between network nodes. Multiplex Section layer entity, not switched
  - No client signals are directly mapped into the OPUCn. They must first be mapped into an ODUk (including ODUflex), which is then mapped or multiplexed into the OPUCn.
  - Components of the interface signal go through the same fiber and optical switches (OMS)
  - The physical layer of the OTUCn signal will depend on the interface.

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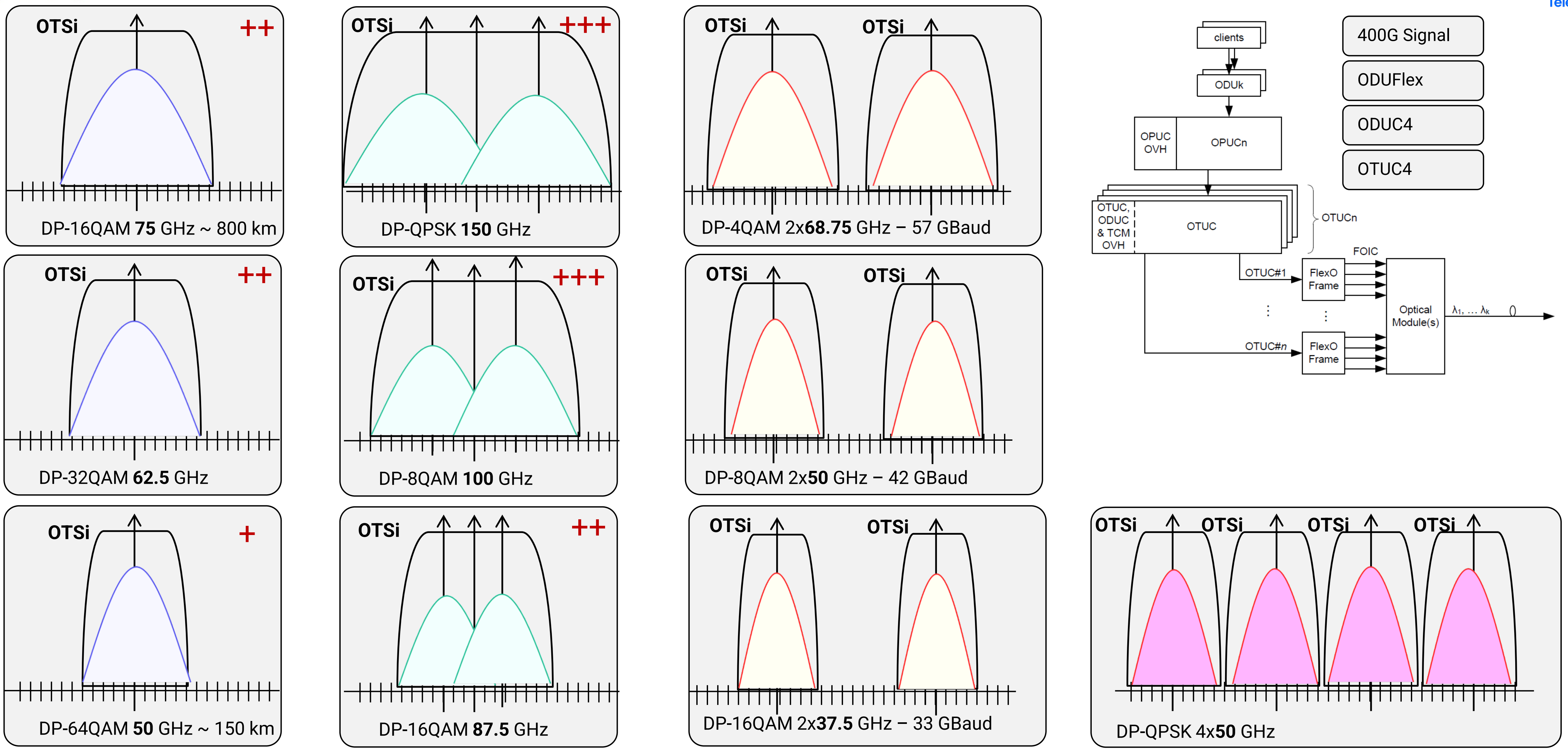
Example: Optical Flexibility with 400Gb/s signal



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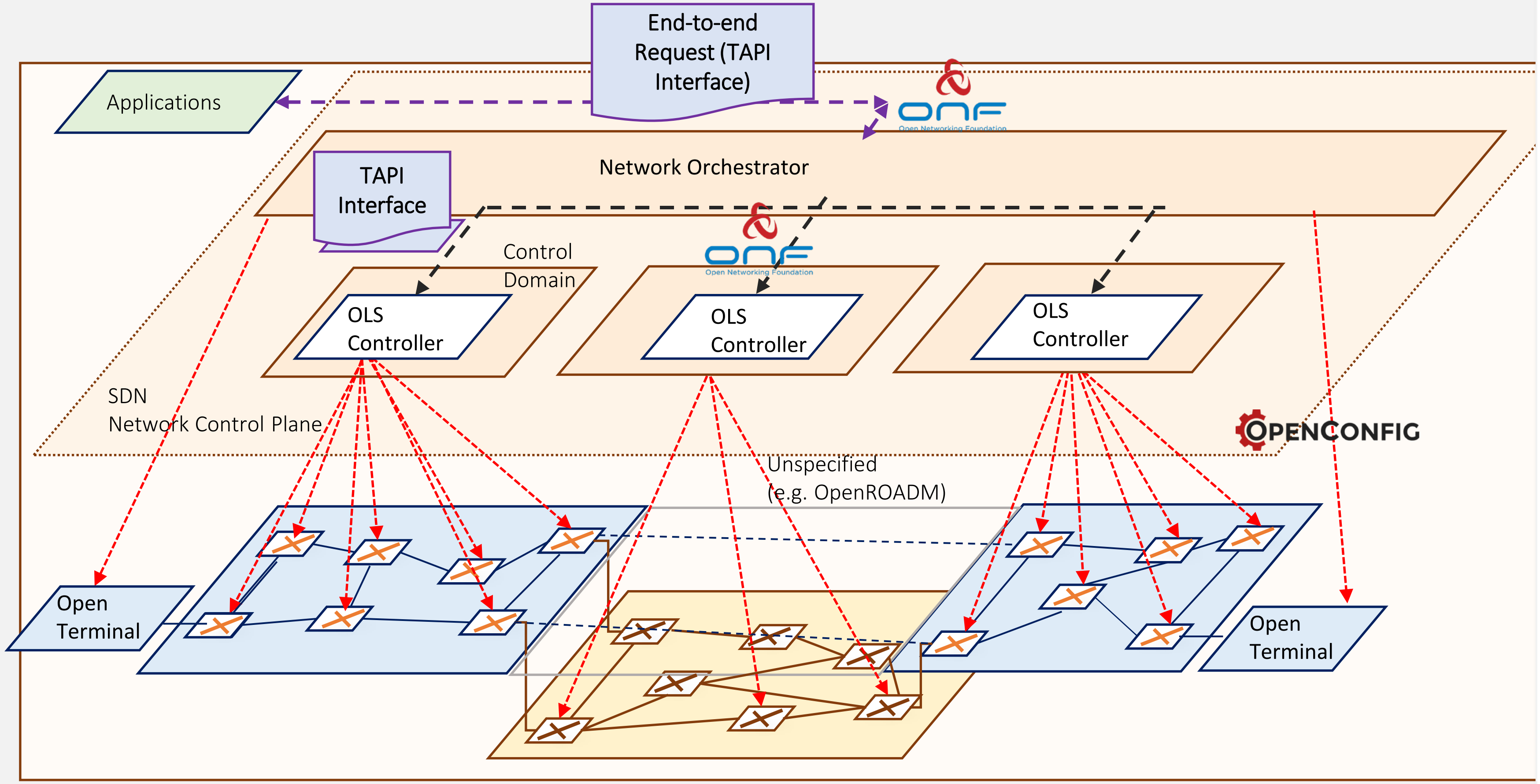
Common Refence Scenario



Specification

Which model(s) can be used ?

SBI specification for OT → OpenConfig

NBI specification for SDN Controller → T-API

Telecom Infra Project (TIP)

Disaggregated Optical Systems(DOS) and

Mandatory Use case requirements for SDN for Transport (MUST)

The main objective of MUST is to accelerate and drive the adoption of SDN standards for IP/MPLS, Optical and Microwave transport technologies, through: SDN common architecture; Agreed standard APIs; Commonly defined use cases

TAPI Reference Implementation Agreement (TR-547)

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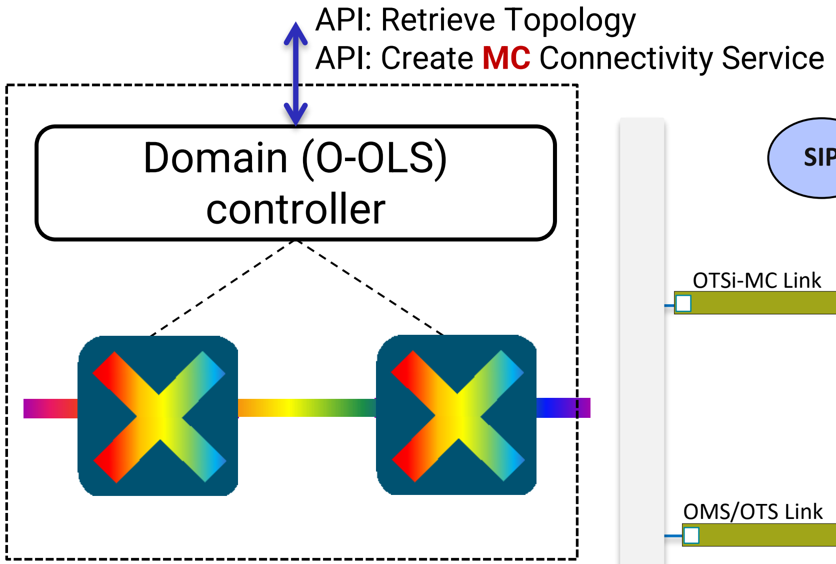
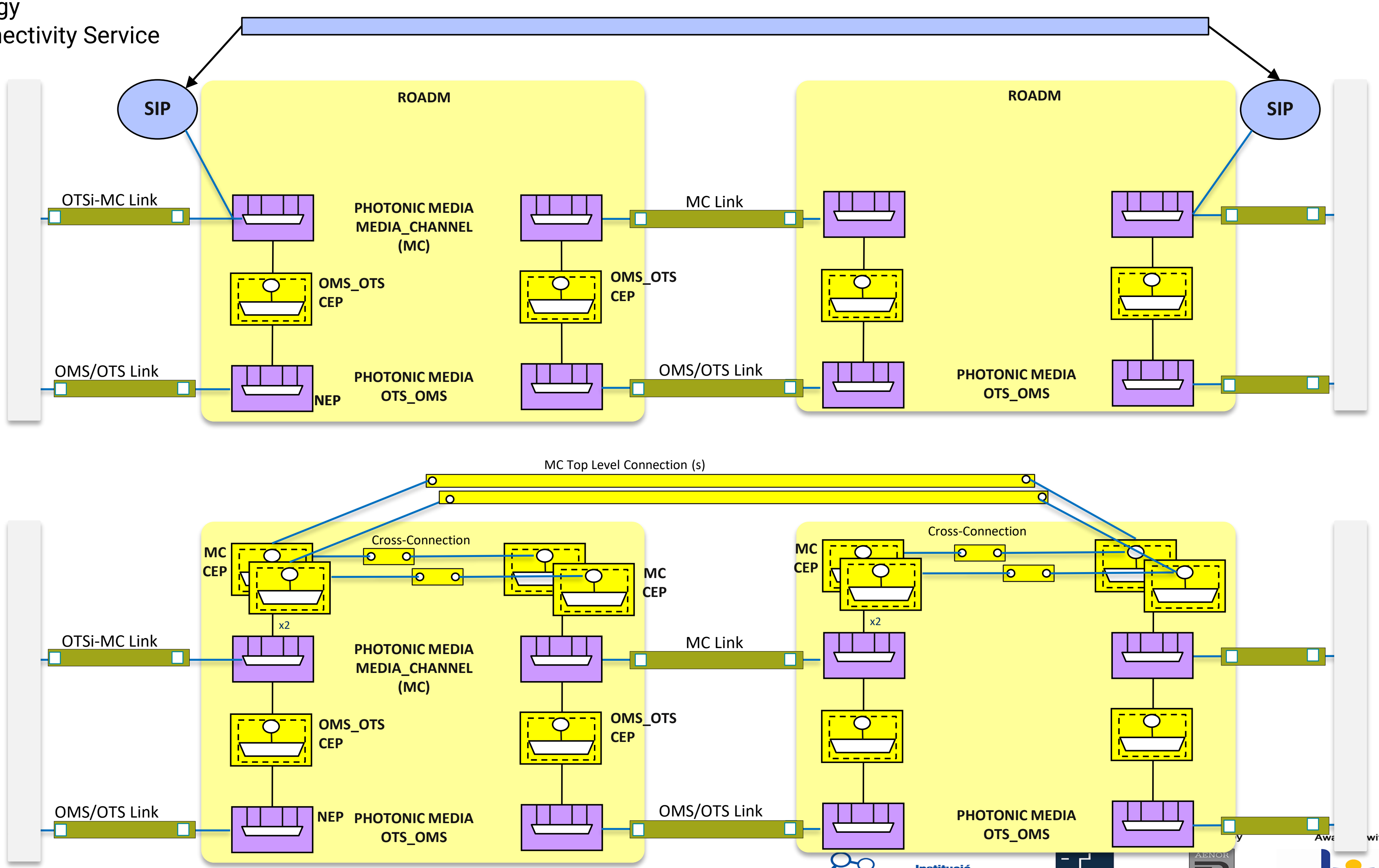
T-API enabled OLS

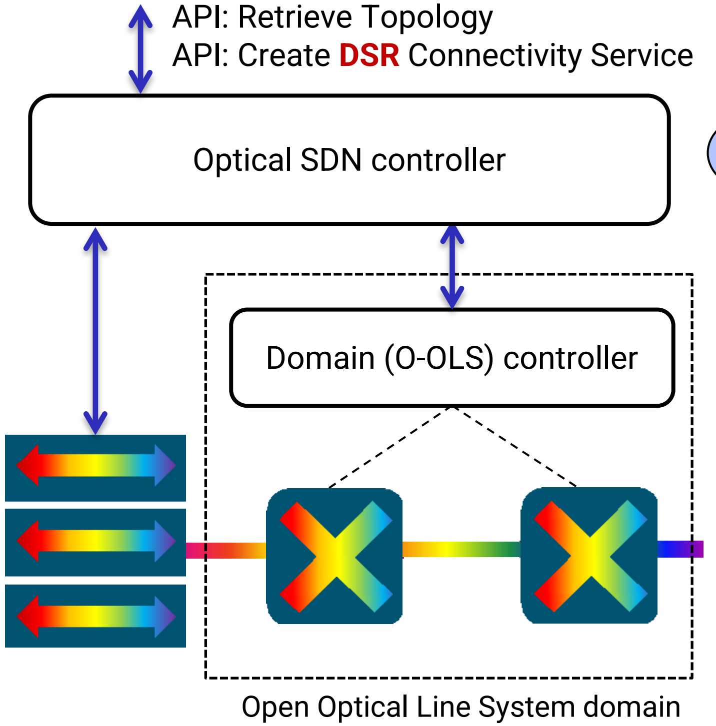


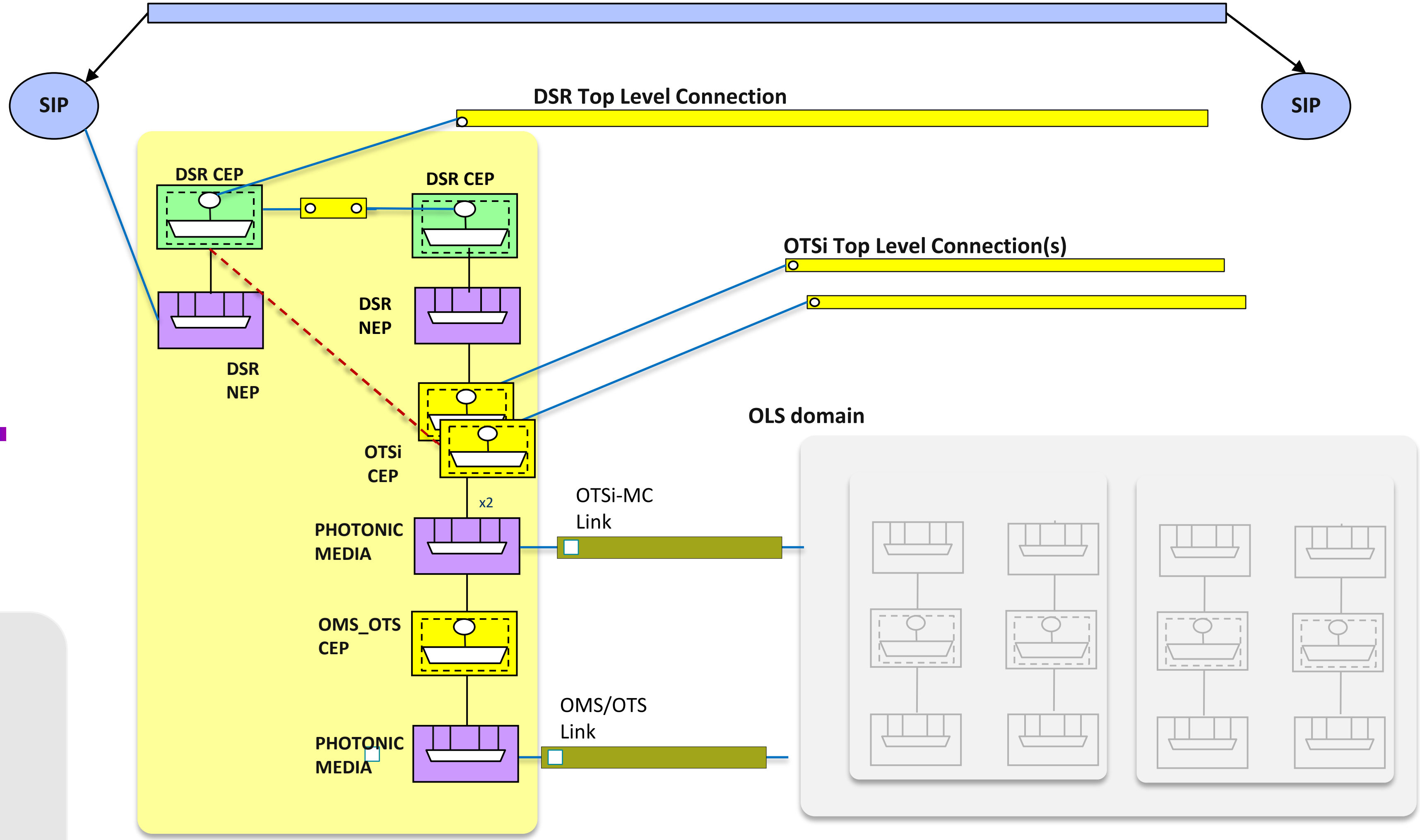
Open Optical Line System domain A



SIP	Service Interface Point
NEP	Node Edge Pont
CEP	Connection End Point

T-API enabled Optical SDN Controller





Coordination O-OT / O-OLS

- O-OT Supported operational modes
- O-OT Tunability restrictions
- OLS Media channel capabilities
- Power Management
- (launch / att / sensitivity)

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Ongoing work: Use Case Definition(s)

- Significant work at the definition of common use cases and how to use the interface / protocol
- See, for example
  - ONF TR-547 “TAPI v2.1.3 Reference Implementation Agreement” (1.0, 1.1 To Appear)
    - https://opennetworking.org/wp-content/uploads/2020/08/TR-547-TAPI-v2.1.3-Reference-Implementation-Agreement-1.pdf
  - ONF TR-548 “TAPI v2.1.3 Reference Implementation Agreement - Streaming” (To appear)
- Arranged by function:
  - Discovery - Inventory Management
  - Connectivity Provisioning
  - Resilience
  - Planning and Maintenance
  - Notifications, Streaming, Telemetry -Including Fault Management

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Open Optical-Terminals (O-OTs)

Open Optical-Terminals
Terminal Devices

Covers transponders, switchponders, muxponders, etc. *“Ability to switch and multiplex multiple client signals into optical signals”*

OpenConfig data model significantly adopted across industry actors

Open Source SDN Controller implementation (e.g., ODTN project)

WHAT?

Current Status
Industry Support

Interoperability events show high level of compliance of OpenConfig models

- Uniform components hierarchy.
- Multiplexing stages and Cross-connection logic discovery is widely implemented.
- Optical channel configuration (Frequency, power and operational mode) supported.
- Ongoing work in performance indicators.

NETCONF and gNMI

- Subscription and notifications for performance streaming telemetry.
- Interoperability issues: SSH key exchanges, different OC yang versions, support for candidate datastore…

HOW?

New Requirements
Progressive adoption

Flexible assignment of tributaries to line ports, with different multiplexing stages (Logical channel cross-connections).

Accounting for hardware capabilities and constraints.

Flexible selection of operational modes

Flexible configuration of optical layers

Need clarification on current model usage, best practices, guidelines, reference implementation agreements

NEXT?

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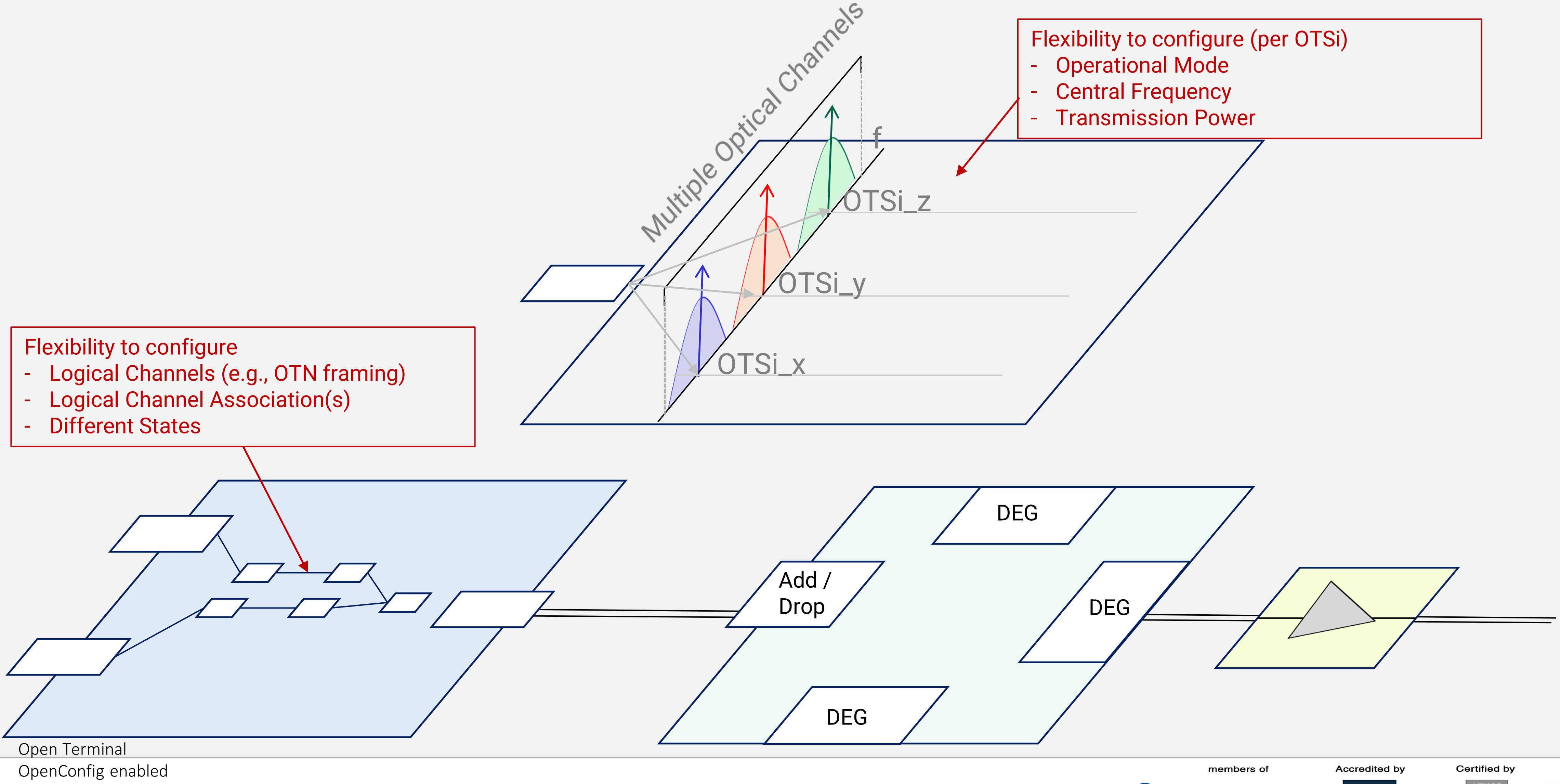
B100G implications: Open Terminal Support of OTSiA



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Physical Impairments & QoT Validation: introduction

- Threats: Lack of common, standard and open data models
  - Has limited innovation in terms of physical impairment modeling.
  - Current systems need to interop with heterogeneous monitoring info sources.
  - Proprietary and costly simulation tools difficult to interop or integrate.
  - Hard to reach consensus of common data models.
- Opportunities
  - Open-Source planning and computation tools are becoming available: Net2plan, GNPy,…
  - Currently, active development in IETF CCAMP/TEAS working group, ONF T-API,…
- Challenges: Modeling in terms of
  - Open Terminals *operational modes*
  - Attributes of network elements and fibers (SSMF) etc.

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Physical Impairments & QoT Validation: aspects

Data Modelling
Physical Layer Impairments (PLI)

- Mandatory to consider PLI
- Extend Topological and Inventory / topological / physical models

Increasing Requirements
- Ability to define complex models
- Support extensibility/augmentation

Standard Models for devices
- "Reach consensus"
- Target wide adoption

MODELS

Algorithmic
Improved algorithms

- Enable advanced/open Phy-Aware RSA

Procedural
Improved Workflows / Use Cases

- Enable new use cases such as the dynamic configuration of amplifiers, terminal operational modes, etc.

Architectural
External Tools

- Enable third-party software tools for QoT path validation or path computation / RSA-

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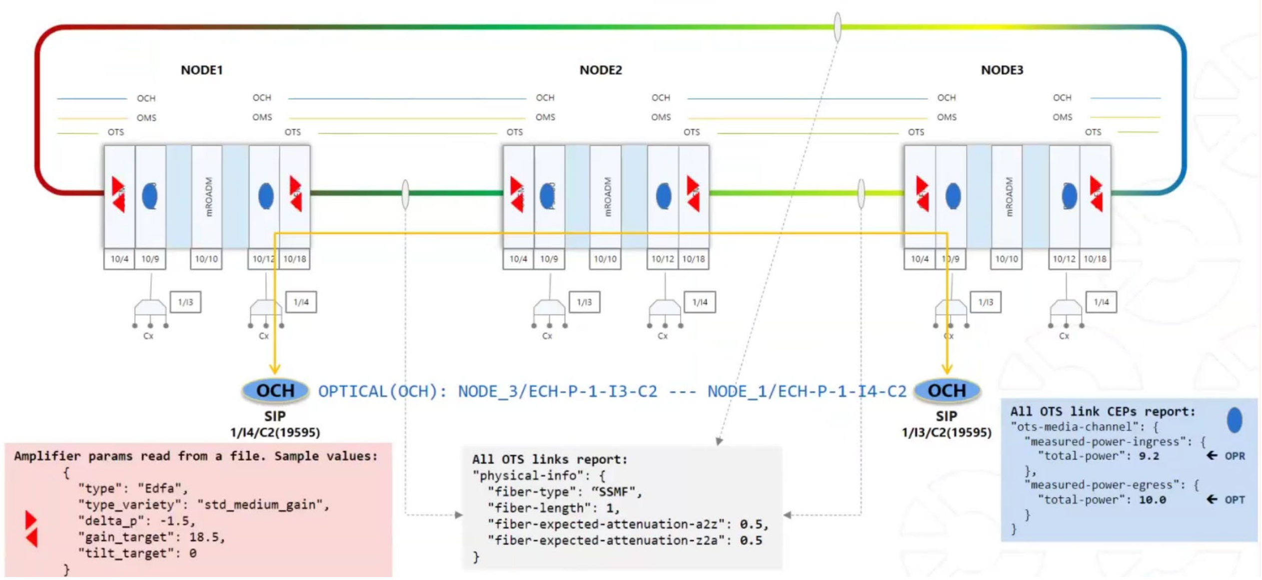
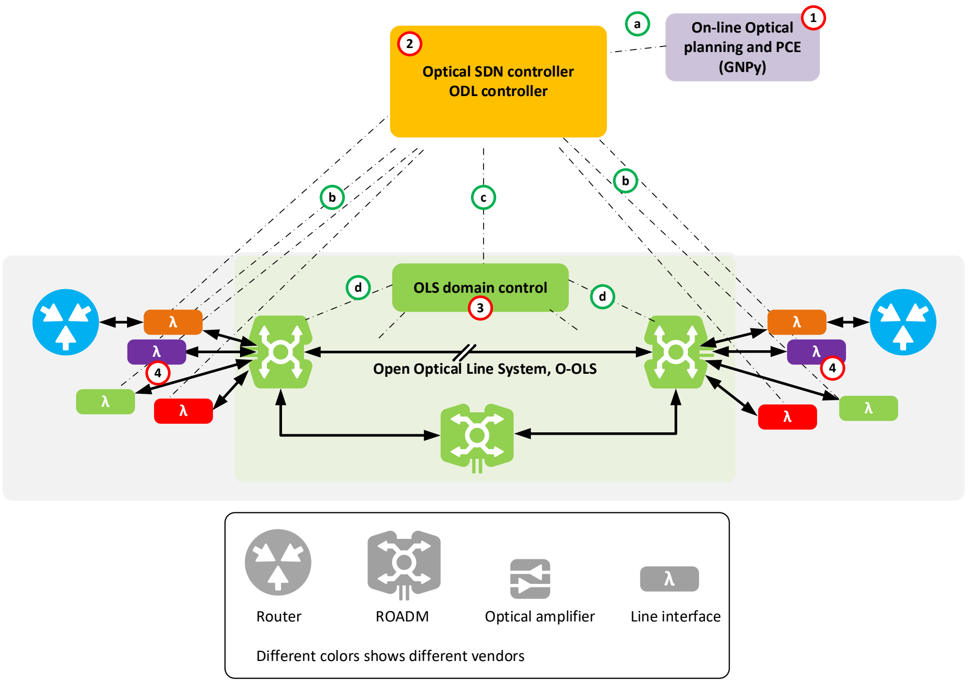
Example: TIP / CANDI PoC

The Telecom Infra Project (TIP) Open Optical and Packet Transport Project Group has announced the successful demonstration of open optical networks control and management by the Converged Architectures for Network Disaggregation & Integration (CANDI)

- TIP / CANDI PoC successfully demonstrated
  - OFC2021 Demo Zone
- PoC Objectives
  - Focus on feasibility, current basic extensions
  - Need to consider long-term solutions
    - Align different activities across SDOs





E. Le Rouzic, A. Lindgren, S. Melin, D. Provencher, R. Subramanian, R. Joyce, F. Moore, D. Reeves, A. Rambaldi, P. Kaczmarek, K. Weeks, S. Neidlinger, G. Agrawal, S. Krishnamoha, B. Raszczyk, T. Uhlar, R. Casellas, O. González de Dios, V. Lopez, "*Operationalizing partially disaggregated optical networks: An open standards-driven multi-vendor demonstration*", in Proceedings of OFC2021 Conference, Virtual, June 2021.

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T-API extensions in support of GNPy (or equivalent…)

Mid-Term Goal

Gap-analysis and extension(s)

Capability, Resource & Topology discovery

- A TAPI client shall be able to retrieve required information from TAPI context and project it as inputs for GNPy.
  - Physical/Equipment/Inventory, Topological and Connectivity-related elements.
- Mapping TAPI elements and attributes to GNPy inputs.

Connectivity Service provisioning with GNPy outputs

- Reflect GNPy output into TAPI-enabled network / device configuration covering the TAPI PHOTONIC_MEDIA layer and OTSi/MC/OMS/OTS protocol/layer qualifiers

Dynamic Connect. Service modification / adjustment

- Based on GNPy output changes and continuous operation

WHAT?

Initial Use Cases

Covering Basic functionality

Perform QoT estimation for a (potential) OTSi service

- Validate OSNR/BER for a path.
- Operational mode, path, devices, frequency slot(s), … are provided as inputs

Compute a path for a potential OTSi service and target QoT (OSNR/BER)

PLI-aware Routing and Spectrum Assignment (RSA)

May require dynamic configuration of amplifiers

HOW?

Roadmap

Work Item in ONF TAPI WG

Using existing consolidated models

(e.g., OpenConfig / IETF) when appropriate.

Define additional uses cases as defined in TIP MUST and TAPI RIA

Targets:

TAPI Release 2.4+

NEXT?

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Gap: Operational modes (OpenConfig/IETF/…)

Sample Extension to model an Open Optical-Terminal

Describe in detail a given operational mode

```
+--ro operational-mode-capabilities
       +--ro description?                          string
       +--ro modulation-format?                    modulation-format
       +--ro modulation-format-proprietary
       |  +--ro description?   string
       +--ro bit-rate?                             bit-rate
       +--ro baud-rate?                            decimal64
       +--ro min-osnr?                             decimal64
       +--ro grid-type?                            grid-type
       +--ro adjustment-granularity?               adjustment-granularity
       +--ro otsi-media-channel?                   decimal64
       +--ro effective-media-channel?              decimal64
       +--ro central-frequency-min?                uint64
       +--ro central-frequency-max?                uint64
       +--ro fec
       |  +--ro fec-coding?               fec-coding
       |  +--ro fec-coding-proprietary
       |  |  +--ro description?   string
       |  +--ro gain?                     decimal64
       +--ro min-output-power?                     decimal64
       +--ro max-output-power?                     decimal64
       +--ro input-power-sensitivity?              decimal64
       +--ro min-q-value?                          decimal64
       +--ro chromatic-dispersion-tolerance?       decimal64
       +--ro differential-group-delay-tolerance?   decimal64
       +--ro filter
       |  +--ro shape?      string
       |  +--ro order?      uint32
       |  +--ro roll-off?   decimal64
       +--ro sop?                                  String
```

```
+--ro properties
       +--ro property* [name]
          +--ro name      -> ../config/name
          +--ro config
          |  +--ro name?    string
          |  +--ro value?   union
          +--ro state
             +--ro name?           string
             +--ro value?          union
             +--ro configurable?   boolean
```

Other References to be considered:

- draft-ietf-ccamp-optical-impairment-topology-yang-06
- draft-esdih-ccamp-layer0-types-ext-00

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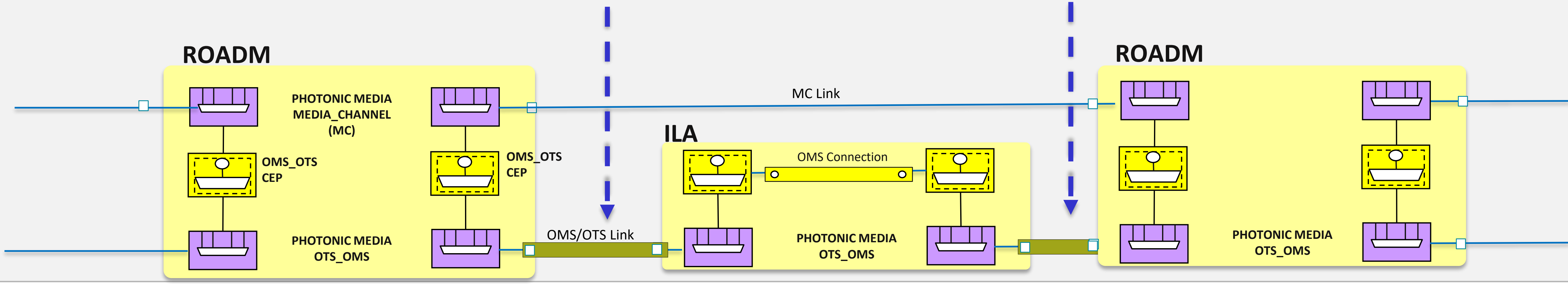
Gap: Characterization of OMS/OTS links

IETF draft-ietf-ccamp-optical-impairment-topology-yang-06#section-2.4

OTS/OMS links

```
+--:(fiber)
|  +--ro fiber
|     +--ro type-variety    string
|     +--ro length          decimal64
|     +--ro loss-coef       decimal64
|     +--ro total-loss      decimal64
|     +--ro pmd?            decimal64
|     +--ro conn-in?        decimal64
|     +--ro conn-out?       decimal64
```



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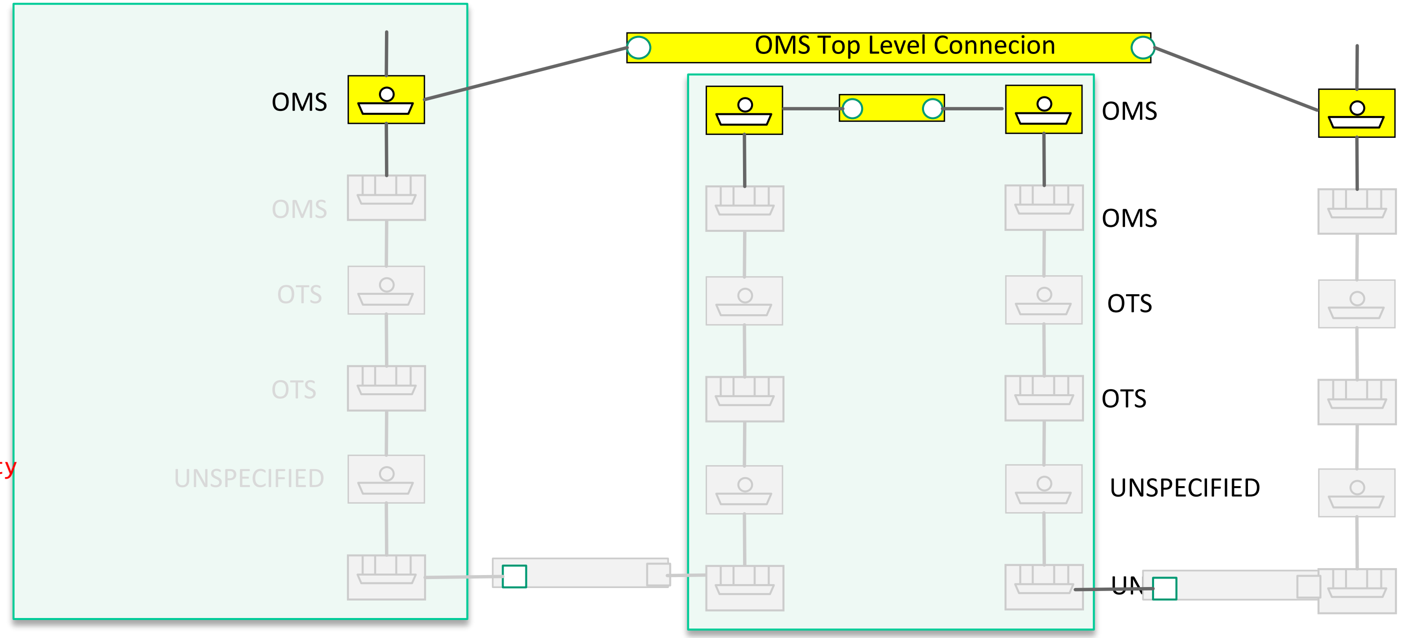
Gap: Amplifier Capabilities and Current State

```
augment …tapi-connectivity:connection-end-point:
   +-- media-channel-connection-end-point-spec
      +-- oms-cep-pac
      |  +-- media-channel-spectrum-pac* [local-id]
      |  |  +--ro occupied-spectrum
      |  |  |  +--ro upper-frequency?        uint64
      |  |  |  +--ro lower-frequency?        uint64
      |  |  |  +--ro frequency-constraint
      |  |  |     +--ro adjustment-granularity?   adjustment-granularity
      |  |  |     +--ro grid-type?                grid-type
      |  |  +-- local-id             string
      |  |  +-- name* [value-name]
      |  |     +-- value-name    string
      |  |     +-- value?        String
      |  +--ro amplifier-spec
      |  |   +--ro amplifier-band-capability* [index]
      |  |       +--ro index                 uint64
      |  |       +--ro mode                  <mode-type>
      |  |       +--ro upper-frequency?        uint64
      |  |       +--ro lower-frequency?        uint64
      |  |       +--ro frequency-constraint
      |  |          +--ro adjustment-granularity?   adjustment-granularity
      |  |          +--ro grid-type?                grid-type
      |  |       +--ro current-gain          decimal64
      |  |       +--ro current-tilt?         decimal64
      |          +-- …
      |  +-- media-channel-power-pac
      |     +--ro measured-power-ingress
      |     |  +--ro total-power?              decimal64
      |     |  +--ro power-spectral-density?   decimal64
      |     +-- measured-power-egress
      |        +-- total-power?              decimal64
      |        +-- power-spectral-density?   decimal64
```



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SDN Control Multiband and SDM sys.: Drivers and motivation

- Multi-band systems and band division multiplexing (BDM):
  - Extend optical spectrum used by wavelength division multiplexing (WDM) to the entire set of available low-loss bands (U, L, C, S and O) in standard single-mode fibers (SSMFs)
  - Potentially needs upgrades on the transceivers, optical amplifiers and ROADMs

- Space division multiplexing (SDM) transmission to exploit the spectral and the spatial dimension of the fiber (i.e., frequencies, cores and modes):
  - SDM super-channels, by exploiting multicore fibers (MCF), multimode fibers (MMF), combining cores and modes in few-mode multicore fibers (FM-MCFs), or by deploying bundle of SSMFs
  - SDM switching for providing spatial paths beyond point-to-point transmission.

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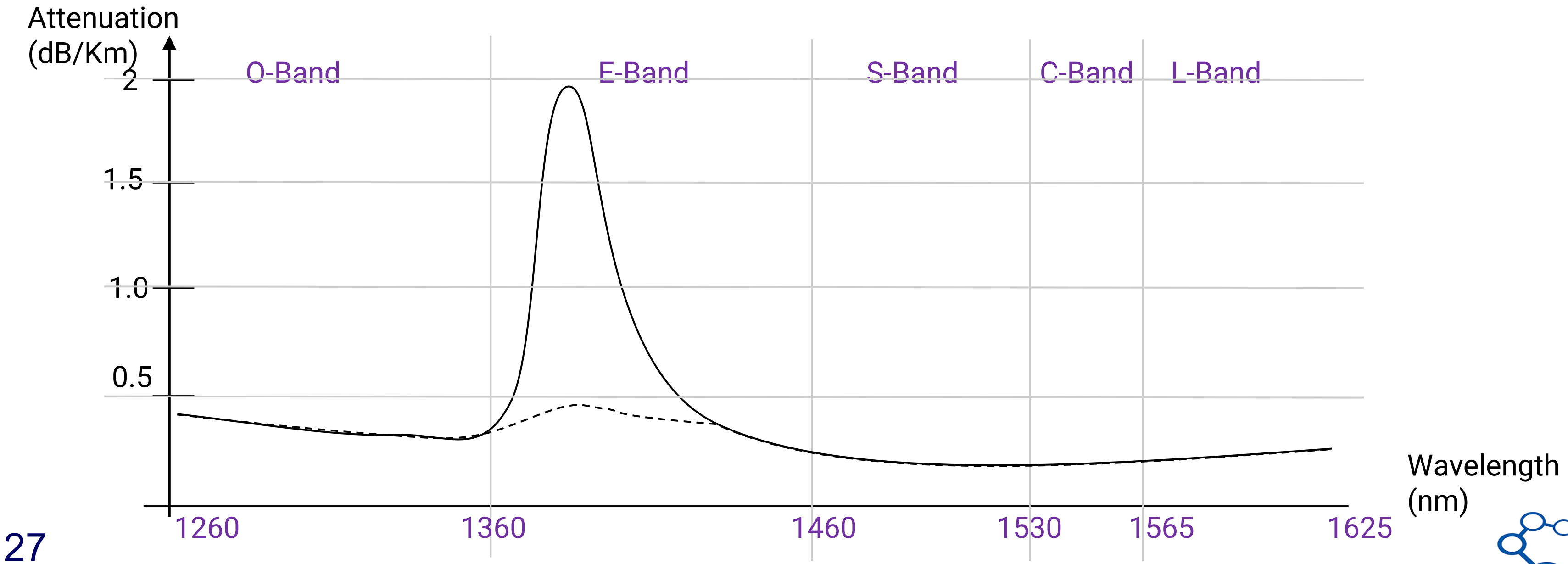
Multi-band networks: Introduction

- Widely deployed C-band networks (low attenuation, EDFA,…)
  - SDN Implementations may assume a single OTS/OMS with a single frequency range
  - Quasi-Uniform behavior for all channels within the band (e.g., reach)
- Need to account for
  - A variable number of arbitrary bands – frequency ranges
  - Band effects and constraints - Hardware limitations



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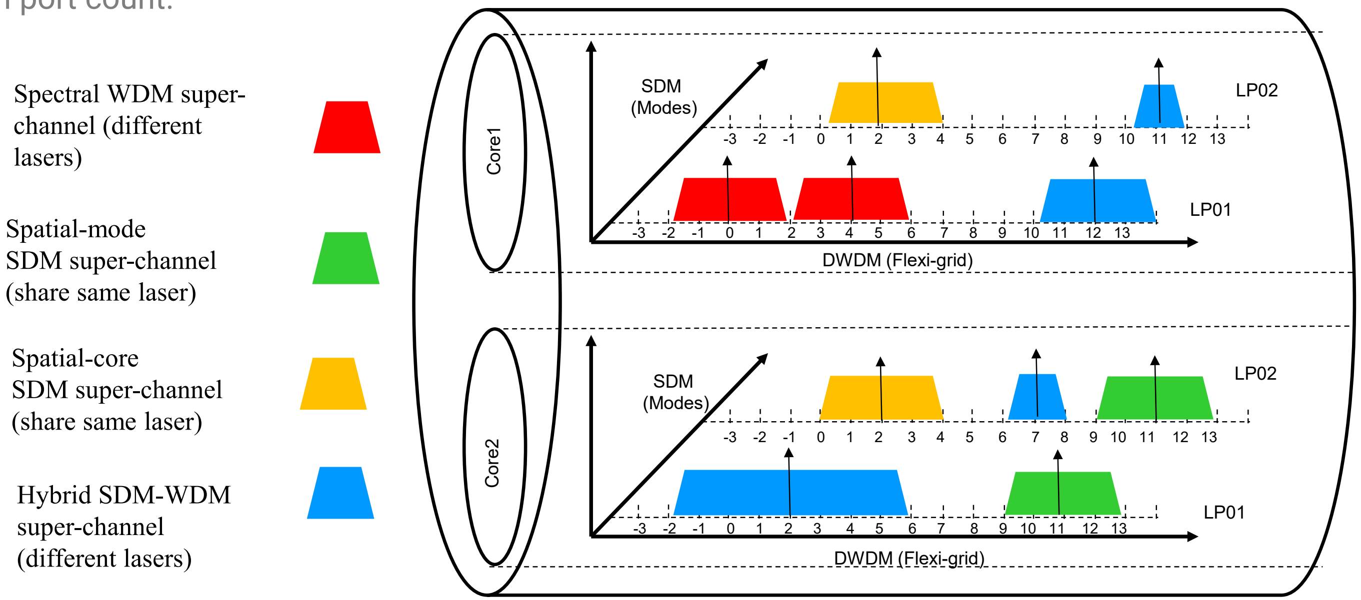
Space Domain Multiplexing (SDM)

- SDM via single-mode fiber bundles, multicore fibers (MCF), few-mode fibre, …
  - Current efforts focus on link capacity improvement with little consideration of the implementation of switching systems.
    - Strong coupling between different spatial modes, prohibitive WDM switching.
  - Weakly-coupled MCFs
    - C+L band transmission of 19-core fibres for trans-oceanic communications
  - Switching?
    - Fully flexible ROADMs would require WSS with high port count.
    - Core switching

- SDM Super-channels
  - A super-channel is an **association of a set of optical (sub) channels to create a (logical) optical channel** with the desired interface rate.



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Open Issues in SDN control of BDM and SDM networks

- Physical Layer Impairment modelling is a key requirement
- How are different bands ***efficiently*** represented in the SDN Controller?
  - One OMS or multiple OMS entities? / One OTS or multiple OTS? / Supportable frequency ranges?
- Need model extensions for configuration operations
  - e.g., “SDM core” or “SDM mode” cross-connect operation
- Path Computation and RSA processes
  - BDM - Band reach, impairment(s),
  - SDM – Consider Optical channel crosstalk, core coupling (low) and mode coupling
    - Requires MIMO DSP must be applied to undo channel crosstalk and equalize all modes (Full MIMO in coupled MMF) or mode groups (Partial MIMO in weakly-coupled MMF)
    - All modes or group of modes must be jointly routed from the source to the destination nodes along the same path in order to perform joint MIMO DSP equalization

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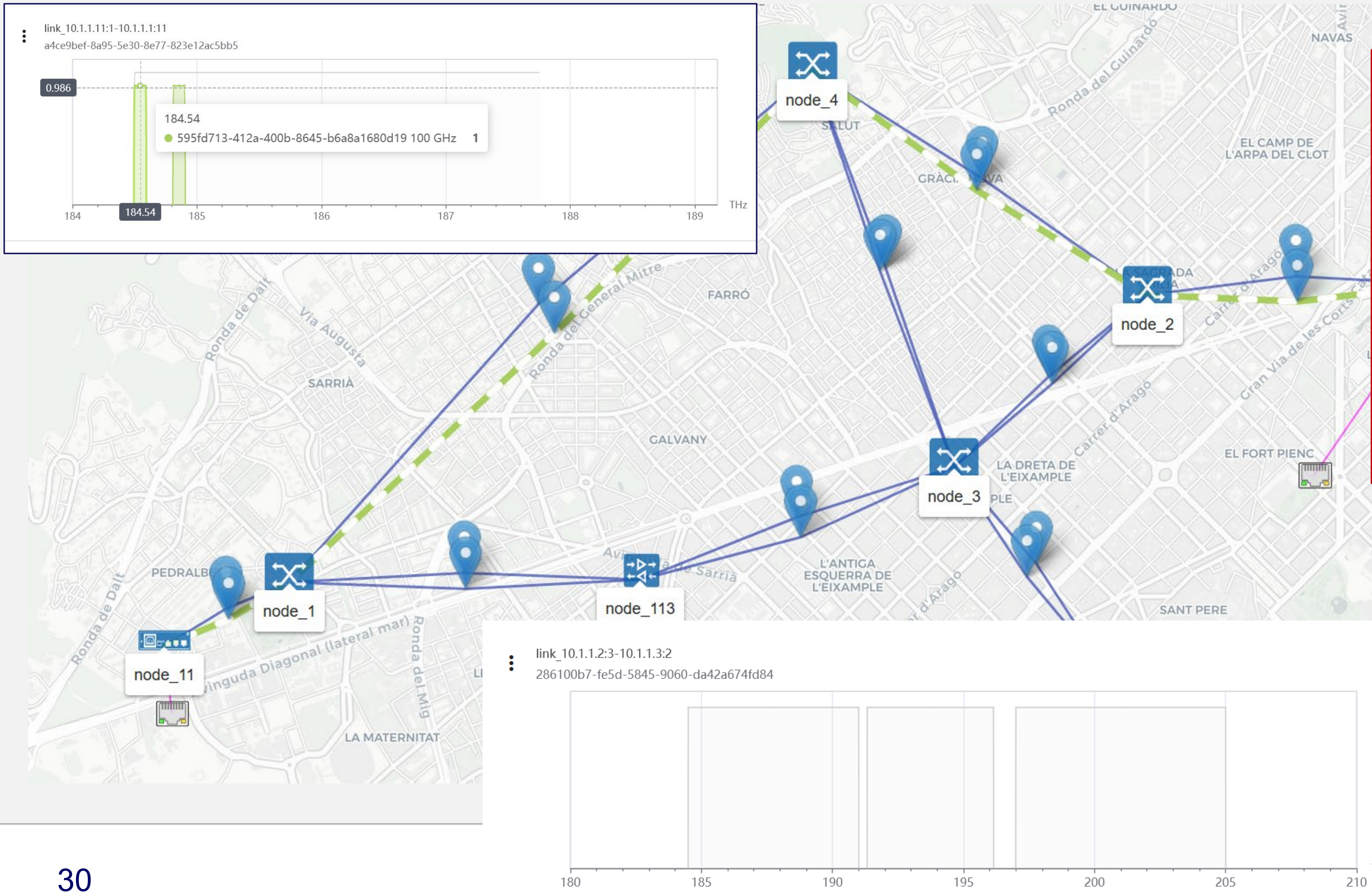
Example: S + L + C Band Support at the Node Edge Point (NEP)




```
"tapi-photonic-media:media-channel-node-edge-point-spec" : {
   "mc-pool" : {
       "available-spectrum" : [{
             "frequency-constraint" : {
                 "adjustment-granularity" : "G_6_25GHZ",
                 "grid-type" : "FLEX"
             },
             "lower-frequency" : 184493750,
             "upper-frequency" : 191006250
          }, {
             "frequency-constraint" : {
                 "adjustment-granularity" : "G_6_25GHZ",
                 "grid-type" : "FLEX"
             },
             "lower-frequency" : 191325000,
             "upper-frequency" : 196150000
          }, {
             "frequency-constraint" : {
                 "adjustment-granularity" : "G_6_25GHZ",
                 "grid-type" : "FLEX"
             },
             "lower-frequency" : 196993750,
             "upper-frequency" : 205006250
          }],...
```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Improved Fault Management / Alarms & Performance monitoring

- From an operators' perspective, support of Fault and Performance management is crucial.
  - Fault Management comprise a set of functions that detect, isolate, and correct unusual (faulty) operational behaviors of a telecommunication network and its environment
  - SDN notification subscription service allows several client applications to subscribe to asynchronous notifications about the changes occurred in the network, specifying object-type (i.e., Connectivity-Service, Connection…), networking layer, notification-type (Creation, Change, Deletion, Alarm, Threshold Crossing..)
- Ongoing Work: Fault Management and advanced Alarm Notification Systems Reporting
  - Flexible and extensible alarms notification-types, based on std. values and required attributes
  - For example, TAPI addresses Alarm Event Notifications function (ITU-T G.7710 Section 7.2.11) and based on ITU-T recommendation X.733, Alarm Events can be grouped into categories (Equipment/environment/connectivity, TCA/processing/security)
- Ongoing Work: Ability to retrieve detailed PM data (as part of the modeling work)
  - This applies to the ODU/OUT as well as the photonic media layers

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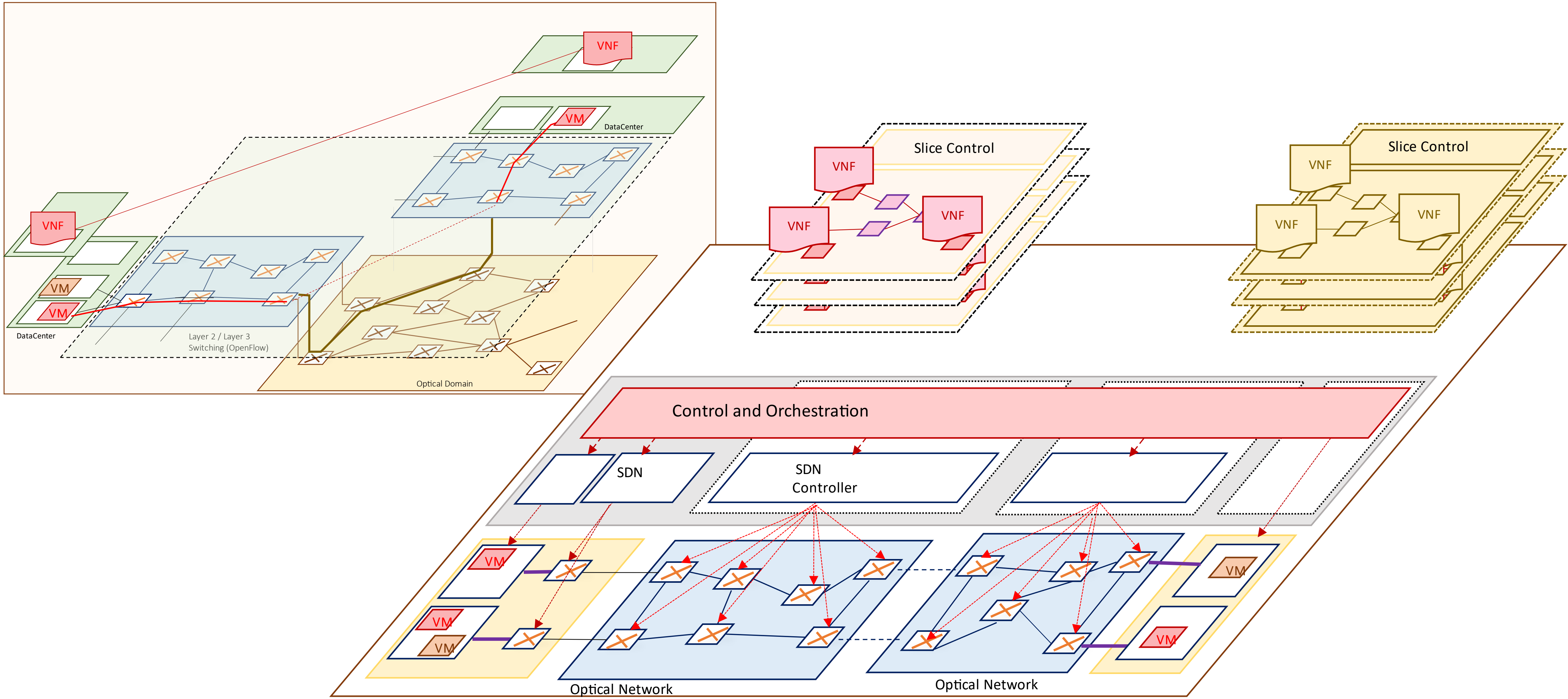
Network Sharing and Virtualization (1)



Overall target: deploy 5G slices across disaggregated infra.

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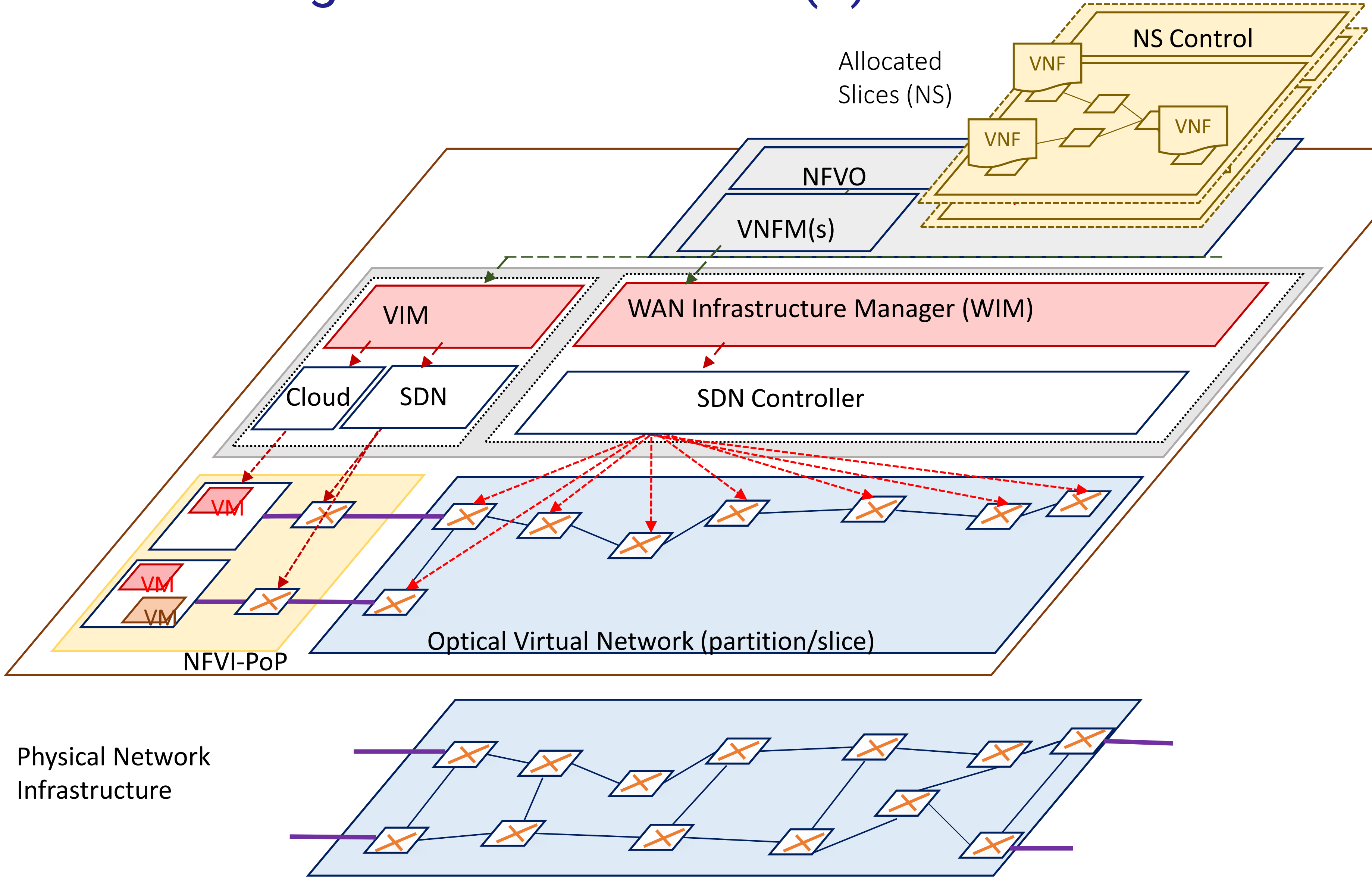
Network Sharing and Virtualization (2)



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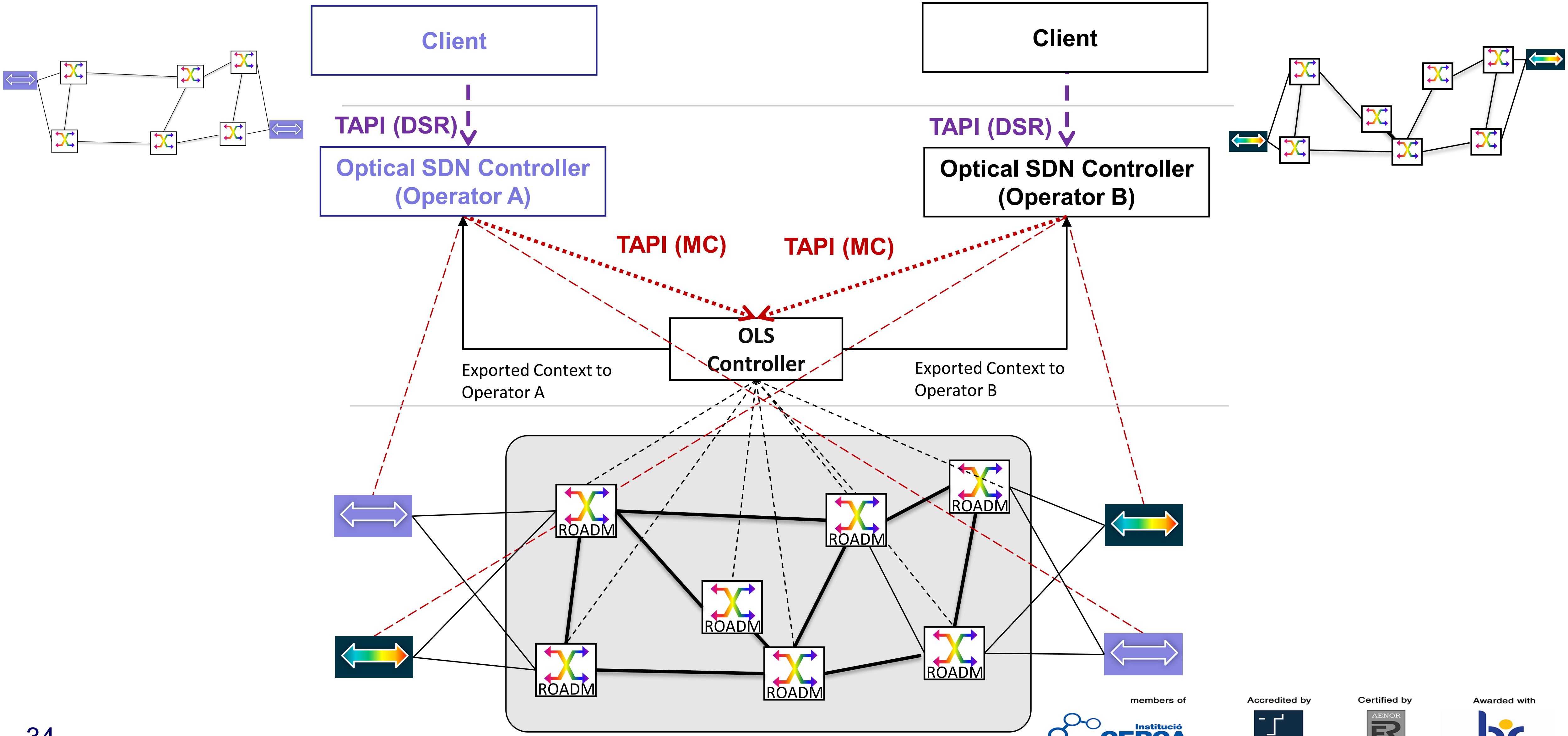
Network Sharing and Virtualization: Spectrum Services



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Optical Monitoring and Telemetry: Introduction

- Operational state monitoring : Crucial for network health and traffic management.
- Issues:
  - Heterogeneity in terms of protocols, data models → Huge integration effort, data model mapping.
  - Heterogeneity in terms of data sources (MIB modules, YANG models, IPFIX flow information, cli scrapping, syslogs records,...)
  - Optical Monitoring in disaggregated networks is challenging
    - OLS systems deals with “express” media channels, yet it may be needed to monitor individual OTSi
    - Need to correlate information from the OLS controller / analog devices and the terminals
    - Physical Layer Impairment, power levels, etc.
- Evolutions
  - Huge increase in application domains related to data-science, machine-learning, autonomous operation…
  - From “monitoring” to “monitoring + streaming telemetry” → Pull (Polling) vs Push
    - Polling (e.g., periodic SNMP GET) is not efficient (but may be the only option). Issues with frequency, resource usage, etc
  - Need to adopt “model-driven telemetry”.
  - Need to cover from “operational telemetry” (time series of a value) to “business telemetry” (business impact, decision making, usage information)

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What is Streaming telemetry?

- "Stream" : A long-lived (typically unidirectional) data flow based on a subscription that is generated by [one or multiple] source(s) according to triggers specified within the subscription.
  - Subscriptions based on models and streamed directly from devices or entities.
  - Telemetry behavior is configured at the source, including model-driven telemetry parametrization.
- Device configuration & enabling a streaming telemetry (e.g., gRPC server, event producer, ...)
  - **Destination-groups**: such as destination addresses, port, transport, and encoding format..
  - **Sensor-groups**: Contain the sensor paths. Sensor path represents the path in the hierarchy of a telemetry YANG data model, specifying the subset of the data that you want to stream from the device
  - **Subscriptions**: Subscription binds the destination-group with the sensor-group and sets the streaming method.
- Basic Telemetry types
  - **Cadence-driven** telemetry continually streams data (operational statistics and state transitions) at a configured cadence. Higher frequency to identify data patterns
  - **Event-driven** telemetry optimizes data that is collected at the receiver and streams data only when a state transition occurs.
  - **Conditional telemetry** Based on configured settings and conditions.

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Optical Monitoring and Telemetry: Aspects to cover

- Telemetry → data collection from "sources" towards a repository
  - Used to be a centralized location → distributed collectors, hierarchical systems
- Current methods
  - Dedicated "yang trees" → polling // Notifications // Yang push // SSE etc...
- Work on Optical Telemetry needs to address multiple aspects:
  - Basic:
    - Telemetry architectures, Data models, Efficient Protocols, and Applications
    - Applicability to Network devices (e.g., Terminals) but also SDN controller(s) and other functional entities
  - Evolving:
    - Scalability - Potentially support thousands of messages per second
    - Support Replay, avoid unnecessary replication, avoid managing too many clients
    - Robustness (Failure of the server, Ensure no message is lost)
    - Features such as full or partial synchronization of state upon reconnect.

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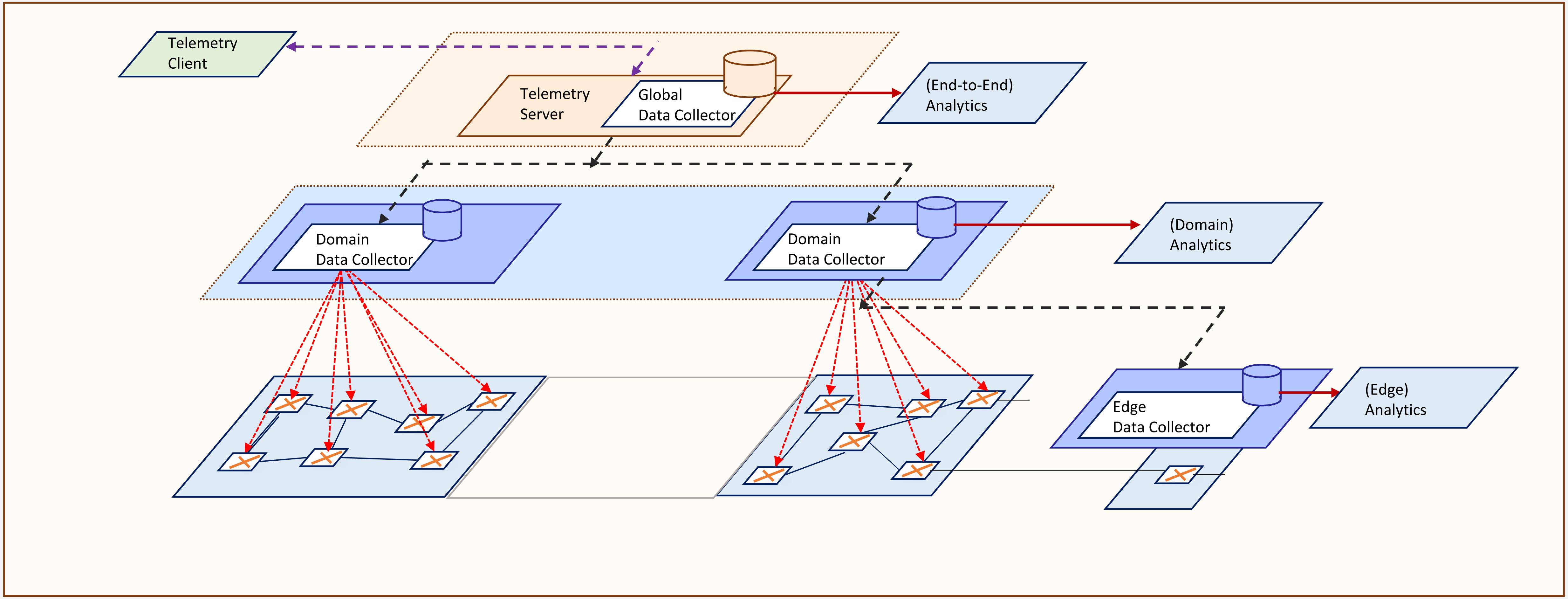
Architectures for Optical Telemetry: addressing scalability



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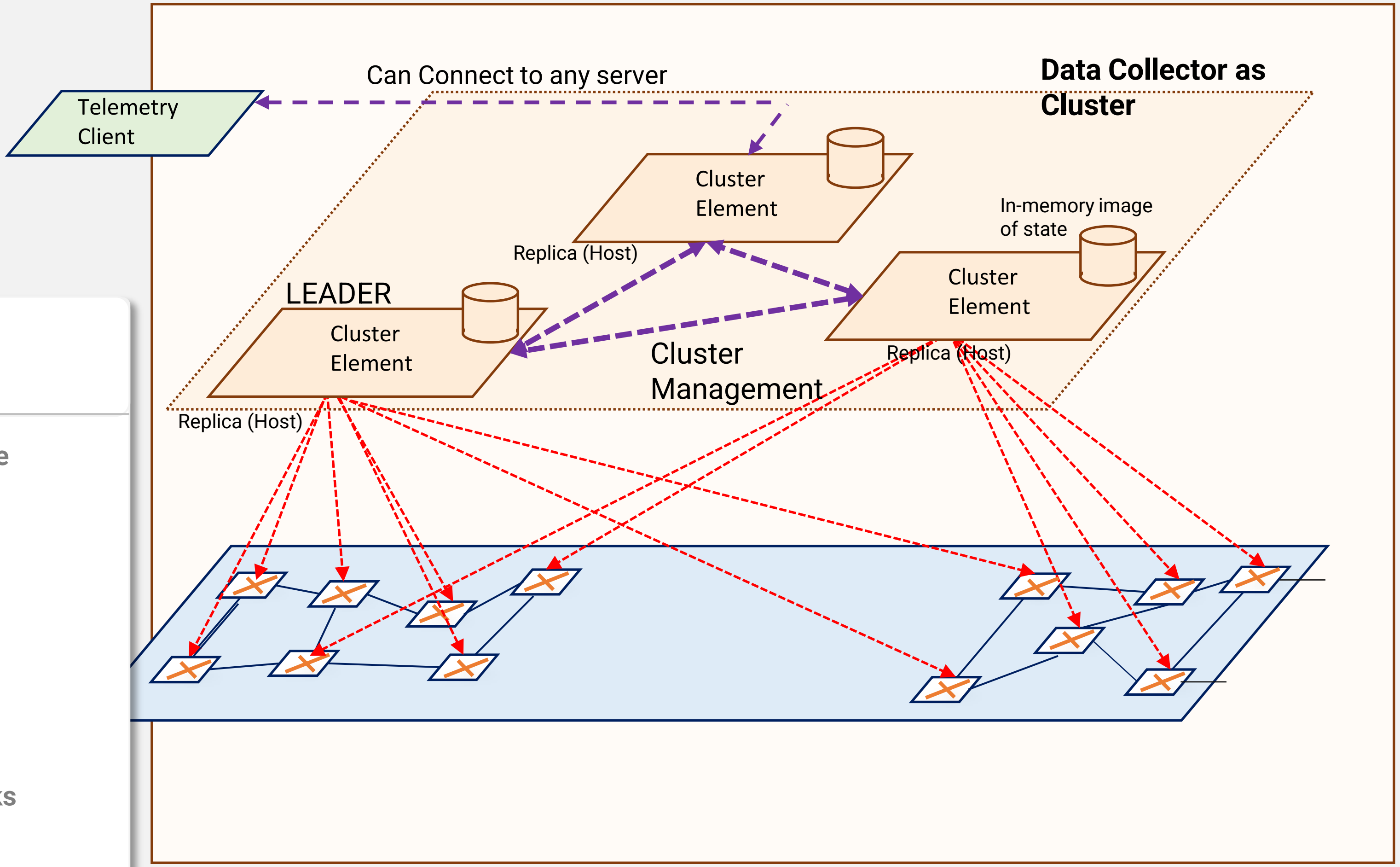
Architectures for Optical Telemetry: addressing robustness



Requirements

- **Coordination Service**
- Synchronization

- **Requirements**
- High-Throughput
- Low Latency

- **Example Frameworks**
- ZooKeper,
- Atomix, …

Guarantees

To construct more advanced uses

- **Sequential Consistency** - Updates will be applied in the order that they were sent.
- **Atomicity** - Updates either succeed or fail. No partial results.
- **Single System Image** - A client will see the same view of the service regardless of the server.
- **Reliability** - Once an update has been applied, it will persist
- **Timeliness** - The clients view of the system is guaranteed to be up-to-date within a certain time bound.

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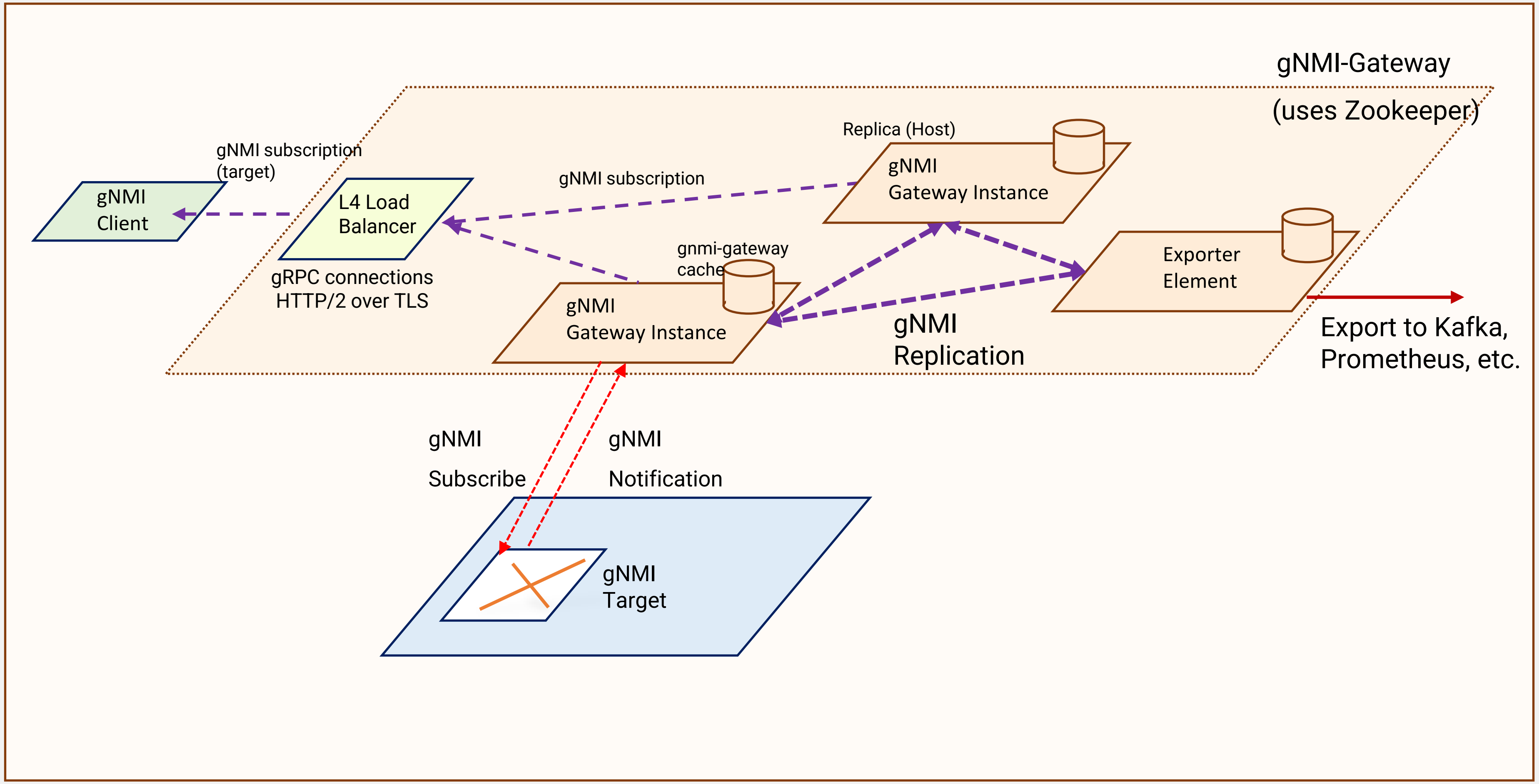
Architectures for Optical Telemetry: Example gNMI-Gateway



Common Use Cases

What is gNMI Gateway for?

- Provide multiple streams to gNMI clients while maintaining a single connection to gNMI targets.
- Provide highly available streams to gNMI clients.
- Distribute gNMI target connections among multiple servers.
- Export gNMI streams to other data formats and protocols.
- Dynamically form connections to gNMI targets

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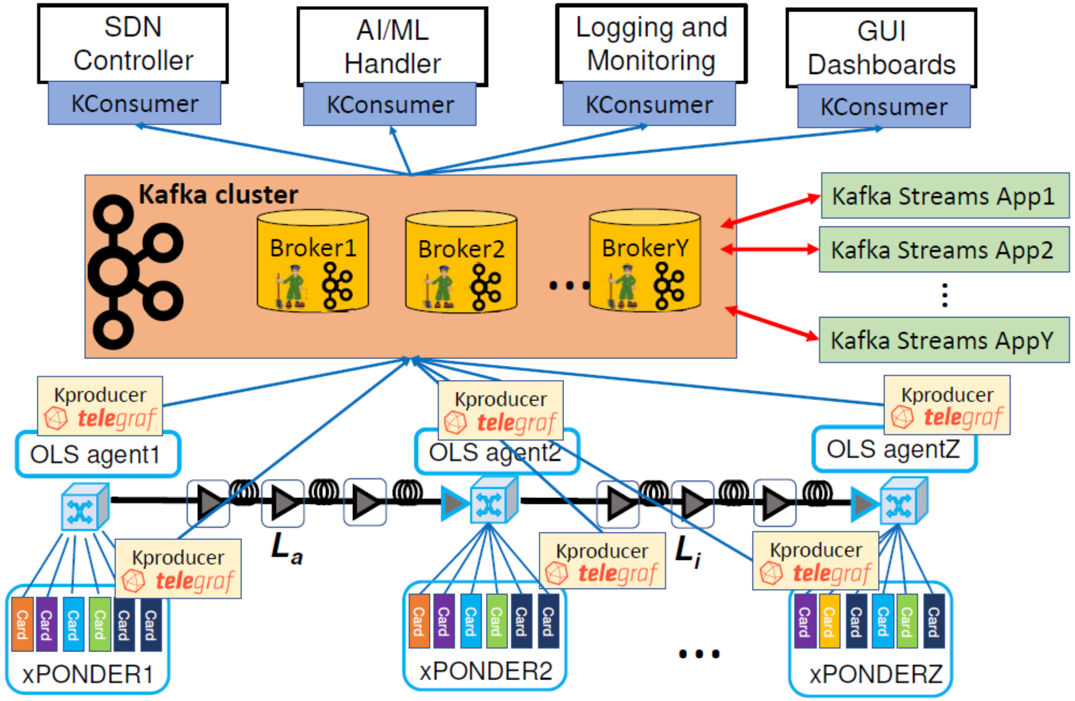
Optical Telemetry: Pub/Sub architectures (1)

- Emergence of new Streaming Platform
  - Publish and subscribe events
  - Store events
  - Process and analyze events – Key, Value, timestamps.

- Event stream
  - Records the history of what has happened in the world as a sequence of events.
  - Ordered sequence or chain of events (infer causality) — new events are constantly being appended to the history.

See Andrea Sgambelluri et al, "Reliable and Scalable Kafka-based Framework for Optical Network Telemetry", May 2021 DOI: 10.1364/JOCN.424639



Andrea Sgambelluri et al, "Reliable and Scalable Kafka-based Framework for Optical Network Telemetry", May 2021 DOI: 10.1364/JOCN.424639

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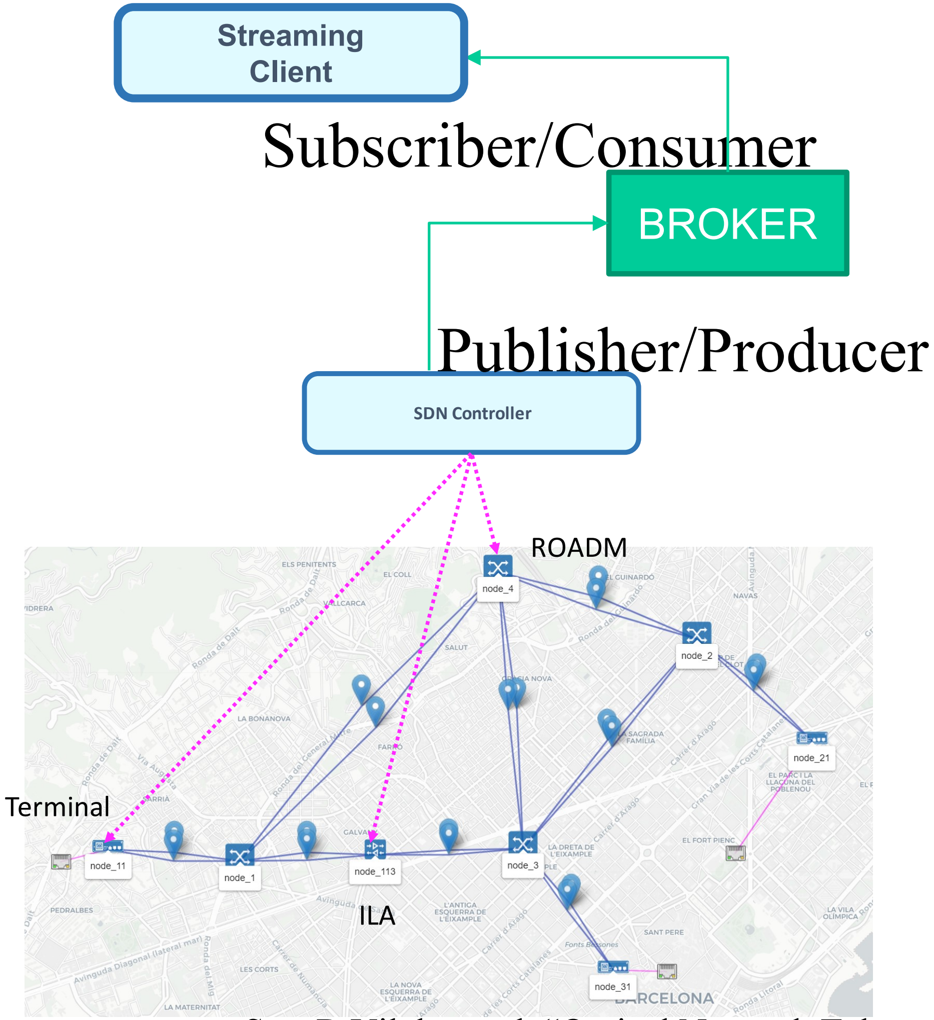
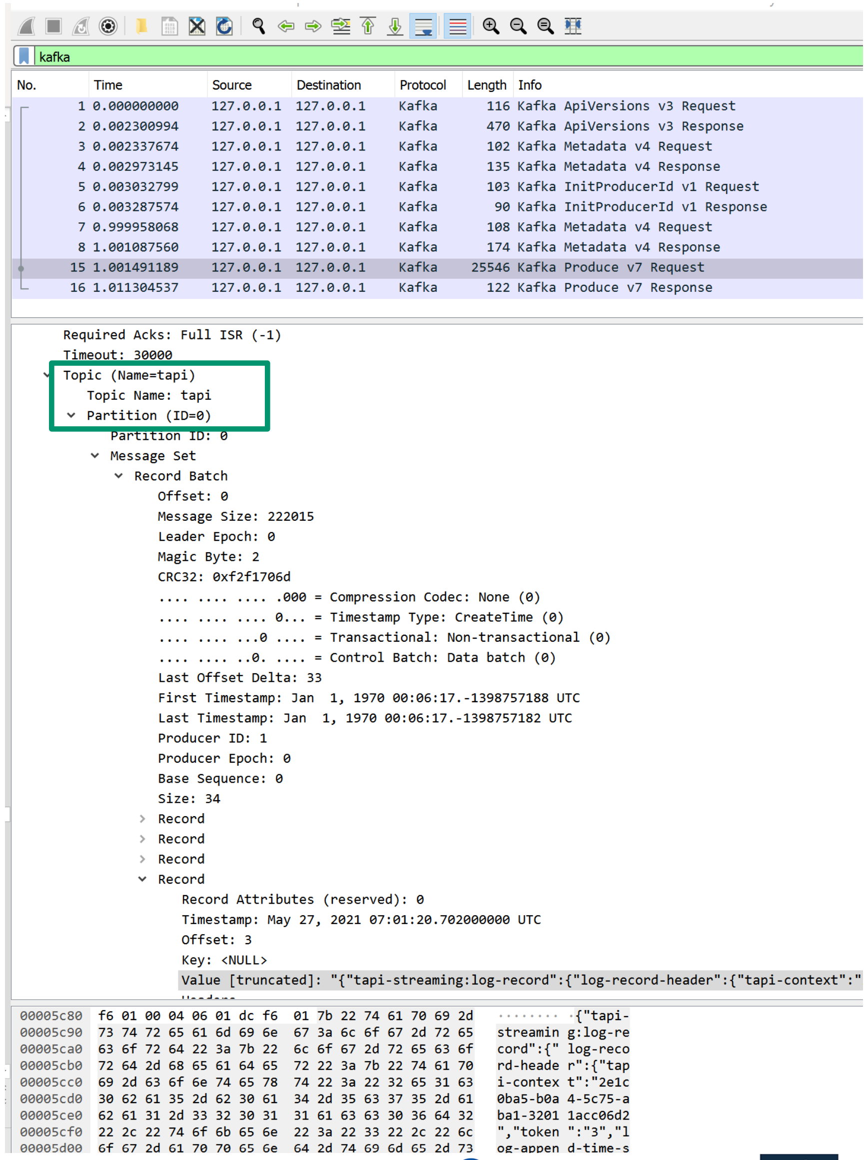
Optical Telemetry: Pub/Sub architectures (2)





See, R.Vilalta et al. “Optical Network Telemetry with Streaming Mechanisms using Transport API and Kafka” , ECOC 2021

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Conclusions

- "Beyond100G" refers to the use of high order modulations, OTU-Cn/ODU-Cn and a new management of the optical (flexi-grid) layer
  - Compromise spectral efficiency / baud rate / bit rate and reach.
  - Need to control the underlying optical infrastructure and programmability.
  - Accounting for Physical Layer Impairment(s) is critical.
- Partial disaggregation
  - Very relevant industry-wise, decoupled costly and upgradeable part (O-OT) and the O-OLS.
- Software Defined Networking
  - Use-Case driven (e.g., TIP MUST, ONF T-API, CANDI GNPy integration).
  - New developments required for optical technologies (multi-band systems, SDM,…).
  - Established role of network telemetry for autonomous networking.

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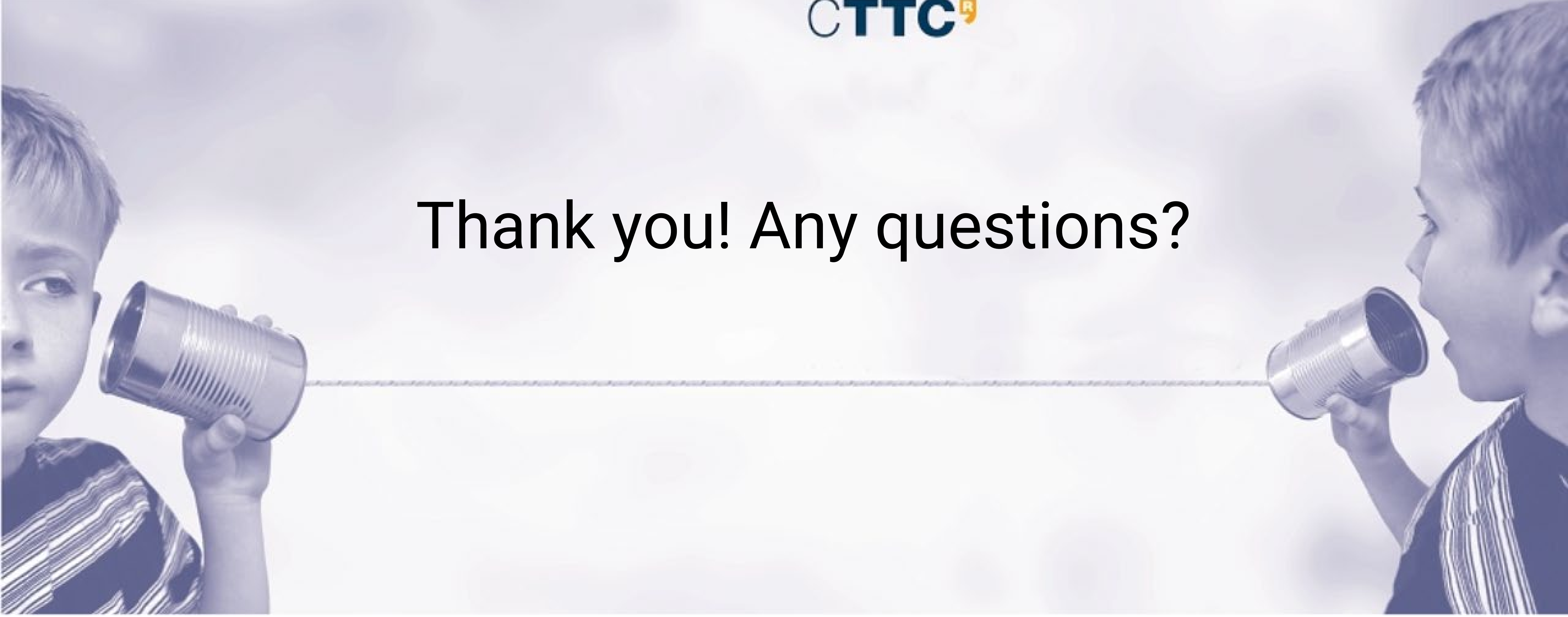
Thank you! Any questions?



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