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Open Transport SDN Architecture Whitepaper

OPEN OPTICAL AND PACKET TRANSPORT SDN INITIATIVE

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GLOSSARY

ACTN	abstraction and control of TE networks
API	application programming interface
BGP-LS	Border Gateway Protocol – Link State
eMBB	Enhanced Mobile Broadband
GUI	graphical user interface
IETF	Internet Engineering Task Force
IGP	Interior Gateway Protocol
ILA	inline amplifier
IS-IS	Intermediate System to Intermediate System
LACP	Link Aggregation Control Protocol
LDP	Label Distribution Protocol
LLDP	Link Layer Discovery Protocol
mMTC	massive machine-type communication
MOP	method of procedure
MPLS	multi-protocol label switching
MW	microwave
NBI	northbound interface
NGMN	Next Generation Mobile Networks
NMS	network management system

NOS	network operating system
OCP	Open Compute Project
ONF	Open Networking Foundation
OTN	optical transport network
ODU	optical data unit
OSS	operations support systems
PCE	path computation element
PCEP	Path Computation Element Protocol
ROADM	reconfigurable optical add-drop multiplexer
SBI	southbound interface
SDN	software defined network
SDO	Standards Definition Organization
T-API	transport API (ONF)
TF	tunable filter
TIP	Telecom Infra Project
uRLLC	ultra-reliable low-latency communication
VPN	virtual private network
VRF	virtual routing and forwarding
YANG	yet another next generation

1 EXECUTIVE SUMMARY

Over the past few years all the telecommunications industry actors, including vendors, network service providers, standardization bodies (e.g., IETF, GSMA), and industry fora (e.g., ONF, OIF, OpenConfig, TMForum) have been working toward the habilitation of automatic network control and programmability. Many efforts have been made to make software defined networking (SDN) a reality, hence a large number of architectural frameworks have been proposed. It's now time to define a common strategy to reduce and select the most suitable standards to unify disparate SDN solutions.

A worldwide, top-ranked network operators group—formed by Telefonica, Vodafone, MTN, Telia Company, DeutscheTelekom, and Orange—has joined efforts to collaborate on open transport SDN within the Telecom Infra Project's Open Optical and Packet Transport (OOPT) project group. They'll be leading a new workstream called MUST (**M**andatory **U**se case requirements for **SDN** for **T**ransport). This white paper presents its common architectural view, the use case-based methodology, and the selection of the most relevant standard interfaces to be implemented by the industry.

The target reference architecture for the transport SDN controllers is hierarchical, with specific domain controllers per technological domain (IP/MPLS, microwave, optical) and a hierarchical controller to provide real-time control of multi-layer and multi-domain transport network resources. The operation support systems (OSS)—including service orchestration and service and resource inventory—will be consuming a set of APIs exposed by the controllers to handle the data and configurations toward end users and enabling service fulfillment.

Based on common use cases defined by the operators, the set of standard SDN interfaces are selected and detailed to produce a common industry specification. The presented SDN architecture enables other systems in charge of planning, inventory, NFV orchestration, service orchestration, performance, or fault management to retrieve information and program the network with well-known, vendor-agnostic interfaces. The SDN controllers will enable resource configuration. The resource abstraction level exposed in the northbound interface (NBI) will depend on the use case definition and the technology considered.

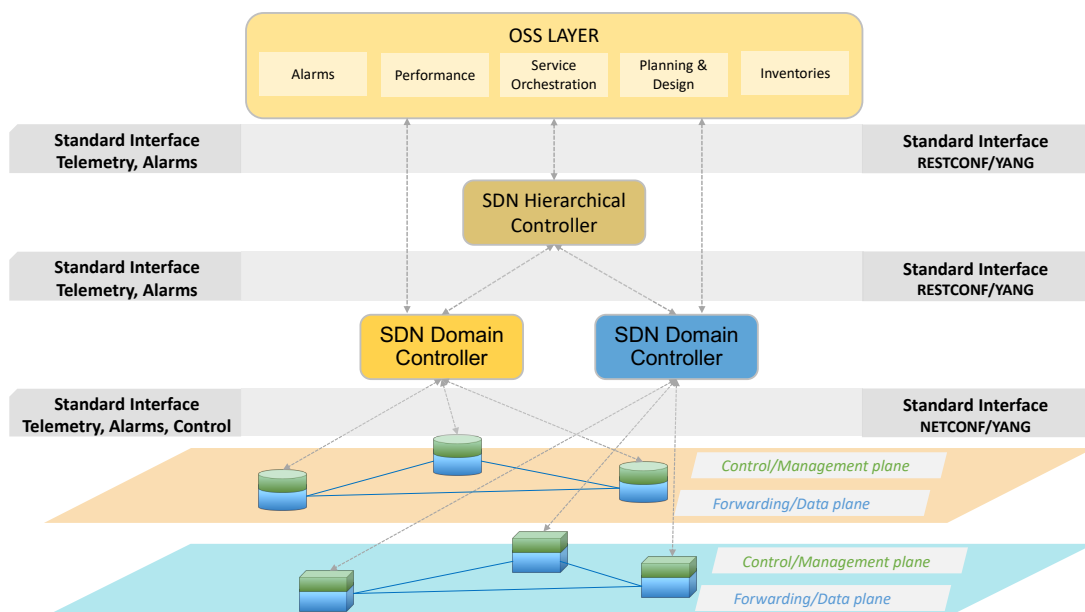


Figure 1 – Open transport SDN architecture vision

Implementing a complete standard specification is a time-consuming process. To accelerate adoption, the operators have compiled the needs of multiple operations, engineering, and planning teams, and have selected the most relevant common use cases. Based on this, technical requirements are prepared and shared with the vendors. These specifications will be incorporated as part of future RFQ processes, which will facilitate a gradual implementation of the defined standards according to a given use case prioritization plan.

To achieve the open programmable transport networks goal, operators will require solution suppliers (both hardware and software—including network operating system and controller software) to include the selected standard interfaces in their commercial product releases, reducing the need for ad hoc development during solution deployment phase.

The operators signing this whitepaper encourage others to join and contribute toward defining and accelerating standardization and implementation of the required SDN interfaces and use cases needed for our transport networks.

2 INTRODUCTION

This document summarizes the open transport SDN strategy with respect to the SDN, together with objectives and activities roadmap needed to accomplish the goal of a full automated IP/optical transport network. This document will not cover technical details associated with SDN [SDN1] and assumes the reader is familiar with the basic concepts.

Over the last few years operators have worked hard on network simplification, aiming to reduce complexity, maintenance needs, and operational burden, while simultaneously producing economic efficiencies within the respective areas. One step ahead, SDN aims to fulfill the same goals by advocating the need to separate the data plane (by transforming network switches to simple packet forwarding devices) from the control plane (by putting a centralized software component, also known as SDN controller, in control of entire network behavior).

It's not foreseen that a complete separation or decoupling of the control plane is required to benefit from the high survivability of networks against failures, disaster recovery, et al. The more practical approach is to enhance network programmability through a hybrid, hierarchical SDN architecture, in which management and control functionalities are split between devices and a set of controllers.

By way of definition, *service* is always considered as the E2E service consumed by an end user and involves several domains and corresponding resources. Management of such services is achieved at the OSS/service orchestration layer. By contrast, the *transport connectivity service* refers to resources handled by the transport domain (IP/MPLS, optical, microwave), and can be considered as a part of the overall service.

The main goals of the SDN approach are:

- **Agile Network Programmability** – Enabling full network automation and reducing time-to-market of service introduction. This is achieved through a dynamic use case-oriented strategy and by standardizing network interfaces.
- **Network Abstraction** – Introducing the adequate level of abstraction at each layer of the architecture (network elements, domain controllers, hierarchical controller), simplifying the development of the OSSes and orchestrators. The first level is moving from a vendor-specific view of networks and devices to a technological one—agnostic from who is implementing the network function. The second level refers to specific use cases, where some device-level behavior is automatically inferred by the SDN control mechanisms. This facilitates interactions among components and therefore overall network automation.
- **Open Transport Networks** – Enabling deployment of open network devices at any transport layer (IP, optical, MW) as suppliers implement the same configuration interface. Controller interfaces will be based on generic functions, not on vendor-specific implementations, thereby reducing the vendor lock-in associated with closed management platforms that were to be used with their own devices.
- **Network Intelligence** – Enabling traffic engineering (TE) and automated service provisioning between layers and vendor technologies.

- **Convergence of control and management** – Where traditional network management systems (NMS) and associated functions will be consolidated in the target SDN architecture.

This paper initially covers the target SDN architecture with the architectural blocks. Use case methodology is explained next, after which the candidate set of interfaces is listed. Operators will work together in choosing and completing the full set of use cases. To conclude, a set of areas where the SDN approach can help operations are presented along with our conclusions.

3 TARGET SOFTWARE-DEFINED NETWORK ARCHITECTURE

This chapter defines the targeted open transport SDN architecture. It's defined based on operators use cases, the reality of operators' networks, and the state of the art of technology. Main architectural blocks are presented first, after which each technology domain is explored based on the current technological evolution.

3.1 Hierarchical Architecture

The preferred open transport SDN architecture within a single operator network is based on a hierarchical controller along with several technology-specific SDN controllers (Figure 2). This set of controllers provides information to the orchestration and support systems. (Multi-operator networks are outside the scope, the assumption being that all technology domains belong to the same operator.)

This approach facilitates the responsibility boundaries for each controller, as well as enables a higher scalability of the solution. In case a transport segment is divided among multiple administrative domains, multiple SDN domain controllers for the relevant transport segment might be included in the hierarchy.

On the other hand, practical implementation of this architecture and potential integration or replication of functional components (e.g., domain controllers or the specific functions to be deployed) will be individually decided by each operator. This three-tier model is aligned with the industry's main architectures, such as ONF *SDN Architecture for Transport Networks* [TR-522], IETF *Framework for Abstraction and Control of TE Networks (ACTN)* [RFC8453], and IETF *Framework for Service Automation* [Wu20].

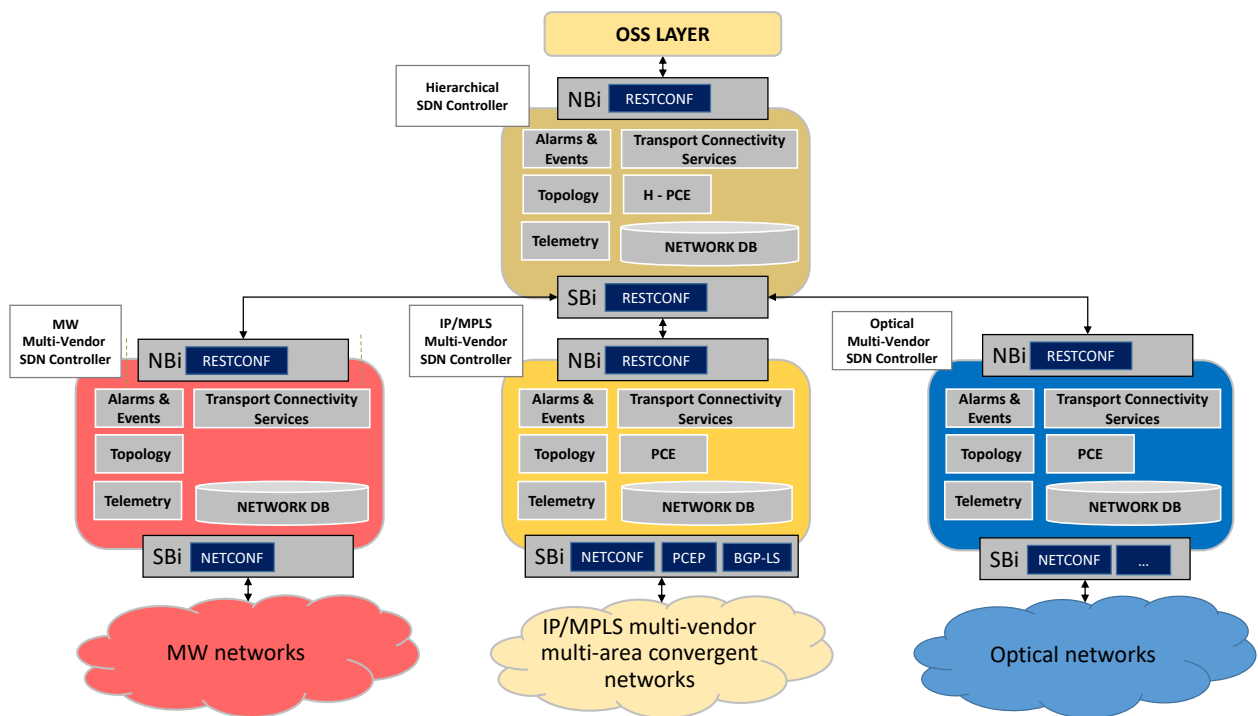


Figure 2 - Open transport SDN target architecture

Due to its wide scope and complexity, the network transport domain is divided into three main technology domains: IP/MPLS, microwave network (MW), and optical. Given their disparate physical layers, each transport technology has unique network element (NE) configuration and service requirements.

Thus, the open transport SDN architecture has foreseen the control separation between technologies by introducing a dedicated domain controller for microwave, IP, and optical transport segments. Each controls a set of network elements through a standardized, technology-dependent southbound interface (SBI) that is also vendor independent.

Each controller also has a northbound interface (NBI) for communication with the hierarchical controller. On top of the SDN domain layer, the hierarchical controller aggregates demands from the management and service layer that includes OSS and orchestration. It exposes a unified NBI, providing resource configuration abstraction and technology agnostic service definitions for consumption.

3.2 Functional Components

3.2.1 Technological domain controller

The SDN domain controllers are required to have a set of common functions independent of the vendor-specific implementations and considered technology domain. These include:

- **Real-time network database** – The controller will take care of collecting data from the NEs (physical and logical), making them available to be queried via NBI for inventory purposes. The set of transport services and the TE information in each domain is also maintained and available for query.
- **Transport connectivity services implementation** – Configuration/modification/deletion of transport service endpoints and their parameters based on requests through the NBI. The level of provided abstraction will depend on the technologies and use cases in scope.
- **Path computation element (PCE)** – Stateful PCE will be used to manage all intra-domain transport connectivity (LSPs) to calculate new LSP paths at service creation, or when traffic optimization is triggered by the operator—with or without TE constraints. The controller also monitors all network LSP statuses. Protection switching is still triggered at a network level by the corresponding transport protocols (e.g., RSVP-TE) to ensure the correct survivability. There is no need for a PCE function in the MW SDN controller as shown in [Figure 2](#).
- **SBI plug-ins** – Protocols needed for communication toward the NEs. For example: NETCONF/YANG for configuration manipulation executed by any SDN domain controller, BGP-LS for collecting TE network topology information, and others depending on use case requirements.
- **NBI RESTCONF/YANG** – Controllers will provide an interface for transport service creation/modification/deletion triggered by the hierarchical controller, but also for notifications of any network changes from the SDN domain controller toward the hierarchical controller.
- **Alarm/Event management** – Alarm and event information can be collected through the NETCONF/YANG directly from the NEs, enabling the controller to perform closed-loop actions against the network (e.g., a specific alarm/event can trigger a PCE calculation for a new, more optimized LSP). Alarms and events are queriable to other fault and performance management systems.
- **Telemetry collection** – Information collected directly from NEs through NETCONF/YANG—or by streaming telemetry (gRPC) feeding the event manager—can trigger network optimization based on operator-defined threshold crossing alerts (TCAs). Telemetry data is made available for controllers and external systems to perform additional closed-loop automations and big data analysis.

- **Real topology view** – The SDN controller, using standard network protocols such as BGP-LS, IGP, and LLDP, maintains a multi-vendor topology view of each domain that can be exposed to the hierarchical controller and network planning applications. Often the controllers provide additional visualization tools and means for exploring network topology.

3.2.2 IP/MPLS multi-vendor SDN controller

IP/MPLS networks are deployed following a hierarchical model and often by mixing equipment from various vendors. Hence, the IP/MPLS routers are interoperable at the data plane level (e.g., MPLS) and control plane level (e.g., routing protocols such as IS-IS, OSPF, LDP, or BGP). For scalability reasons, IP networks are typically subdivided into IGP domains such that routing and control protocols are confined to their respective domains.

The foreseen SDN solution for the IP segment is based on a single, multi-vendor IP SDN domain controller charged with configuring the IP NEs, as shown in Figure 2. The target SBI for vendor-agnostic device configuration must be compliant with NETCONF [RFC6241] standard protocol and follow common specific requirements (e.g., a subset of NETCONF capabilities) that bound the reference implementation of the interface. IP/MPLS networks are formed by multiple domains, and therefore the SDN controller will manage multiple IGP domains to provide a unified view of the network.

The IP SDN domain controller will be the main entry point to the NEs to avoid overloading them and will provide a coherent view of the IP network. It will have a set of standard NBI and SBI plug-ins to receive and process requests to create new transport connectivity services, such as L2 and L3 VPNs. The controller will handle translation of the request to low-level device configurations and transfer it to network devices.

The controller will collect a real-time IP topology by using specific protocols, such as BGP-LS and LLDP. Additionally, it'll have a real-time database containing physical and logical information of each network IP device. Regarding TE use cases, the IP SDN controller will be able to create TE tunnels (with RSVP-TE or segment routing) and optimize the set of tunnels deployed on the network. The controller must support complex scenarios, such as multi-IGP environments.

Some of the functions, such as PCE, can be provided by a standalone controller module. Whenever a function is decoupled from the controller, it needs to be implemented using the standard controller NBI and SBI.

3.2.3 Microwave SDN domain

While microwave (MW) deployment can be applied with some regional criteria (linked in many cases to simplified network operation and more efficient management of aspects such as repair time and spare part oversight), wireless transport networks are often deployed on a point-to-point basis. Therefore it's common to have more than one vendor within any region (even small ones), with a vendor map that changes more dynamically than in other network planes.

MW networks support any typical topology (e.g., ring, mesh, chain), with the most common architectures being hub and spoke—or short chains typically having no path redundancy.

(Diversity schemes or extra channels in same or different bands are in many cases considered on a link basis to add protection capabilities and enhance availability and performance.)

Although the number of hops from the end links to the first fiber aggregation point is progressively shortened (especially with the newest-generation mobile backhaul applications), it's still common for operators to have multi-vendor, E2E MW aggregation paths.

Currently wireless networks are operated through vendor network management systems (NMS) using proprietary interfaces. Operations and configuration/maintenance activities are performed manually and statically. This adds complexity toward the higher level applications and OSS systems that need to manage many proprietary interfaces. In the case of MW networks, these scale upward to non-reasonable levels due to technical complexity.

Integration and management complexity can often be a showstopper that blocks introduction of a new vendor solution that could otherwise be technically relevant for the network. Furthermore, integration costs and efforts caused by diversity in both NMSes and the installed base prevents operators from using advanced applications that could provide more sophisticated features such as power management or multi-layer coordination.

The main driver for introducing the MW SDN domain controller is to reduce such complexity and enable more simplified integrations and operations of diverse platforms. The proposed architecture model is aligned with the view of the multi-vendor SDN domain controller, introducing its domain controller as a vendor-agnostic configurator of the MW network. It focuses on simplifying configuration by leaving the service definition to upper layer applications.

3.2.4 Optical SDN domain

Transport WDM networks from system vendors are deployed on a regional basis, as a result of 1) legacy deployments, 2) technology redundancy, 3) different optical performance requirements (metro vs. long-haul), or 4) commercial reasons. Without line-side interoperability of the disparate WDM transceivers and reconfigurable optical add-drop multiplexers (ROADMs), there is no competitive advantage for a uniform configuration interface of optical devices.

In the short term, optical SDN controllers are expected to provide network programmability and interoperability toward upper layers (multi-layer) and between vendors (multi-domain, multi-vendor) through the support of standard NBIs (i.e., coordination will be provided by the upper-layer hierarchical SDN controller).

This approach will enable 1) setting up and tearing down connections in optical channels (OCh and ODU layers), 2) the discovery of network resources to compose a layered, uniform view based on OTN hierarchy, and 3) optical network monitoring. These standard NBIs should include sufficient details about network resources for the operator to perform its operations (e.g., online planning, diagnosis) based on the view provided by the controller.

In the medium term, direct component programmability is of interest for operators in point-to-point, metro, and regional scenarios, where disaggregation of optical transceivers and line-side components can play an important role. Here, OpenROADM [OpenR] and

OpenConfig [OpenC] projects have already defined device configuration models for transponders and open line systems. The industry is approaching this optical control transformation in two phases:

1. Partial disaggregation – As a medium term objective, the target of the promotion of a standard interface based on NETCONF/YANG that lets an optical SDN controller manage third-party terminal devices (i.e., transponders) that can transmit over the different vendor line system.
2. Full disaggregation – The long term objective is open management of the line system; that is, defragmentation of the optical transport network in vendor islands by the adoption of a common, standardized interface for open line systems (multi-vendor) to be managed by a single optical SDN controller.

3.3 Hierarchical Controller

The hierarchical controller coordinates the information and interfaces of the transport network domain SDN controllers, enabling more advanced use cases. It has E2E visibility of all transport network segments, and exposes an abstracted topology view of resources and the set of available services to clients through its northbound APIs. The abstraction level exposed by the controller can differ according to the needs of the northbound client (e.g., OSS, service orchestrators). Depending on use (e.g., alarms, performance data, detailed domain inventory), the OSS can directly interface to the domain controllers, thereby maintaining architecture scalability.

On the hierarchical controller SBI, each SDN controller will expose vendor-agnostic, network-level programmability and resource discovery functionalities. The SBI is intended, but is not limited, to 1) provide access to a device's configuration data, 2) expose per-OSI layer topology and network inventory information, and 3) offer active monitoring of device configuration changes and network state data (i.e., traffic statistics). Alarm and device inventory information, for FM and RIM respectively, is intended to be managed at the SDN domain controllers in the first phase, but exposure level through the hierarchical controller will also be evaluated.

A main hierarchical controller goal is to automatically provide relationships between layers and offer transport connectivity services involving various layers and domains.

The hierarchical controller's internal architecture can be split into three conceptual building blocks:

- **E2E transport network control** – The functional component inside the hierarchical controller is responsible for providing E2E control by coordinating the disparate technologies through its corresponding SDN domain controllers (OTN/WDM optical network, IP/MPLS core/backhaul, and MW/MBH network). This controller will provide per-layer E2E visualization (i.e., per-layer topology composition) and stateful control of provisioned network services. This includes cross-layer resource relationships, i.e., the mapping between optical carrier connections (OCh) created in L0 and OTN services available in the L1, or (analogously) between L2 links and underlying transport services.
- **Multi-layer PCE** – Computations performed at the domain controller level consider resources existing at the technological layer and the respective domain. However, the multi-layer, active stateful PCE module has the role of computing paths across multiple

technologies (IP/MPLS, optical, and MW) based on multi-layer topology information (see, multi-layer topology composition) and with collaboration of the IP/MPLS path computation element, optical controller, and MW controller.

- **Service binding to transport resources** – By means of the PCE function this enables the hierarchical controller to obtain the best TE connections for a given transport connectivity service. For example, the set of LSPs is computed for a VPN having bandwidth or latency constraints. With a multi-layer view, it can correctly compute disjointness-type of constraints (that could otherwise lead to non-accurate information). It permits the hierarchical controller to assign specific network transport resources to VPN services. In addition to requesting the binding, it lets the hierarchical controller expose the set of transport TE resources in all layers used by a VPN service. This information can be used by assurance systems to track user traffic.

4 AGILE NETWORK PROGRAMABILITY

The daily life of a transport service provider involves a variety of processes requiring substantial interaction with its network. For example, such processes include network planning and creation phases (e.g., strategic planning, tactical planning, capacity planning), in which planners need 1) an accurate view of the topology with different abstraction levels, together with 2) information about already-deployed hardware.

A real-time view of their network is essential to make appropriate decisions; data and measurements need to be as recent and accurate as possible. To achieve this, continuous synchronization between the network and online planning tools is required. As technology evolves, all network potential has to be exposed to create new services and applications with the required speed and agility.

Presently the set of OSSes handling the discovery, activation, provisioning, and fault management processes require either a huge amount of manual inputs or substantial integration with each vendor's technology. Emerging service orchestrators, which manage the lifecycle of E2E services (including access, data centers, virtual functions, and transport), require programmatic interfaces toward the network. With SDN the paradigm is shifting toward a data-driven operation. Here a network element, topology, or service is represented by a software data model, developed in a standardized, vendor-independent way.

4.1 Interface Consolidation

Common operator initiatives include specifications as to how information must be exchanged in the control layers (workflows) and the amount of data required for each use case. Such specifications differentiate between services, network, and device models:

- **Network service models** represent the configuration to create transport connectivity services from the network point of view, including technical details and how the service is implemented. These models include all relevant parameters to set up the service in a vendor-agnostic manner.
- **Network topology models** are the representation of relationships between NEs as discovered by the controller.
- **Path computation models** permit the use of PCE functionalities and request

computations at the relevant technology layer.

- **Device models** translate requirements to device-specific language. They enable configuration of every parameter and function included in a device.

Each model applies to a particular control layer interface. Service models are part of the NBI definitions of the controllers, and device models are part of the NE interface specifications. Thus, a well-defined and standardized set of northbound and southbound interfaces are essential elements for the correct integration between a network and OSS/BSS applications.

4.1.1 Northbound interfaces

OSSes support the main processes of a network service provider (i.e., tactical planning, strategic planning, fault management, B2B delivery, et al.). Today such systems are attached to a network by multiple means; in some cases directly to devices via command line interfaces (CLI) or SNMP (mainly for alarms or metric reporting), and in others through a network management system (NMS).

With NMS, all its functionalities are accessible via its GUI and—as a result of custom developments done for customers—some type of limited NBI might be available. But in many cases the functionality is not homogeneous and is incomplete, what with the interface having been developed in CORBA, MTOSI, XML exchange, or even FTP, and the data model being vendor-proprietary.

This wide diversity in implementations, as well as the lack of completeness of the industry-available NBI between network and OSS, impacts both associated cost and integration lead-time. It becomes an upgrade bottleneck and limits the huge potential of network automation. Current and future efforts should focus on standardizing NBIs per network layer. Doing so would present the network to the OSS as an E2E, multilayer abstracted model, supporting future services and reducing network operating complexity.

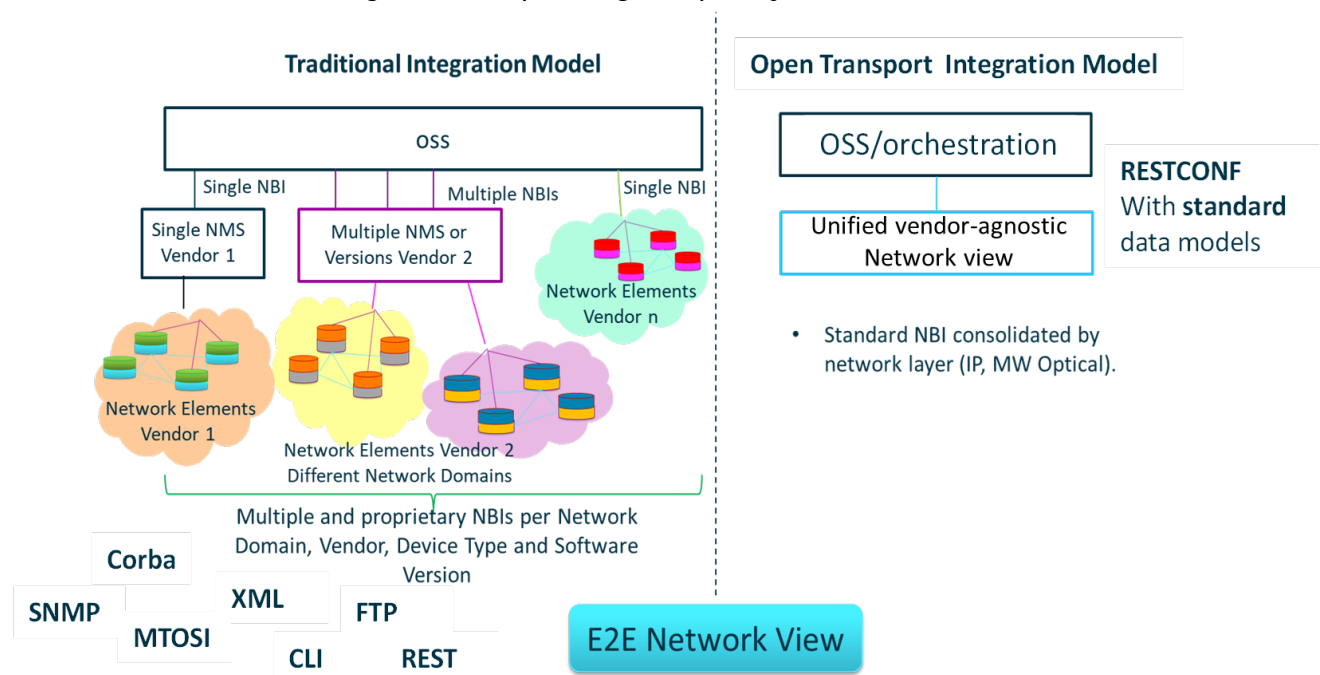


Figure 3 – NBI simplification and vendor-agnostic view

With an architecture to simplify this complexity, open transport SDN proposes to consolidate the interaction between network elements and OSS/orchestrators. State-of-the-art SDN advocates for programmatic interfaces based on standardized data models that can be seen as APIs.

4.1.2 Southbound interfaces toward network elements

In the proposed SDN architecture, the SBI is the interface between a SDN transport technology domain controller (IP/MPLS, MW, or optical) and the NEs. There will be varied approaches for the different layers/networks in terms of SDN domain controllers, and thus a set of SBIs is needed.

While still accounting for technological equipment details and representing a vendor-independent device view, the open transport initiative proposes SBI standardization based on programmatic interfaces. (This avoids the widely used, proprietary CLI approach and goes beyond the eternal SNMP.) Standardization must not only include the communication protocol, but also the data model to be used.

The goal of initiative is to move networks toward a more dynamic, programmable infrastructure by adopting software-defined principles such as declarative configuration and model-driven management/operations. For each technology, a set of models will be selected based on maturity, technical merit, and readiness. For example, Openconfig, IETF, and ONF define vendor-neutral YANG data models.

In addition, not only is the SBI intended to be used for configuration, but also for obtaining up-to-date device information in real time (i.e., telemetry, which also implies no performance impact on any device). This is achieved by streaming of data—compared to classical approaches that burdened device CPUs and had big communications overhead. Such telemetry is a key technology that drives our network decisions.

4.2 Methodology

In order to detail and design the interface requirements, it has been defined a strategy based on to the lifecycle of the operator cases:

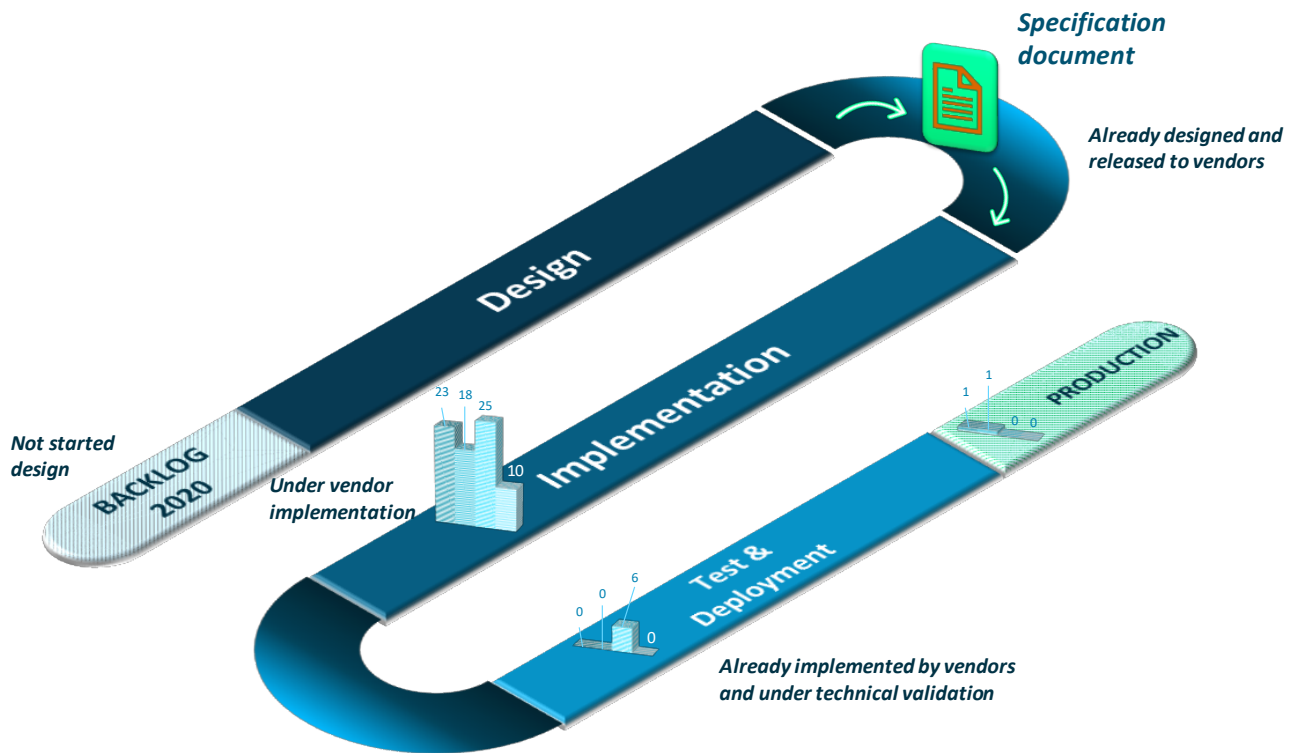


Figure 4 – Use case-oriented strategy

4.2.1 Use case definition

The strategy is based on the definition, validation, and deployment of use cases that will be progressively enriching the SDN ecosystem. Use case design and activation is a continuous process, in which each is defined, modeled, and standardized on a global basis, validated in operations, then extended to the remainder of operations to improve availability times.



Figure 5 – Use case lifecycle

The operators collaborating in open transport SDN are working on common use cases across multiple operations. These are grouped in eight (8) categories. (See Figure 6 for the complete open transport use case taxonomy.) Detailed requirements are analyzed for each and the set of interfaces will be designed (selected and completed if they don't exist or aren't sufficient in number).

Use cases include:

- Common services activation (e.g., VPNs, multicast TV, B2B, optical channels, L2 connections)
- Detailed node configuration reporting for inventory purposes
- Network topology exposure for planning/operation purposes
- Automatic network optimization mechanisms
- Online telemetry information from network nodes to assure service quality
- Alarms reporting and survivability mechanisms
- Automatic device configuration to increase deployment speed
- Operation-driven tasks, such as traffic rerouting when nodes are in maintenance or what-if analysis

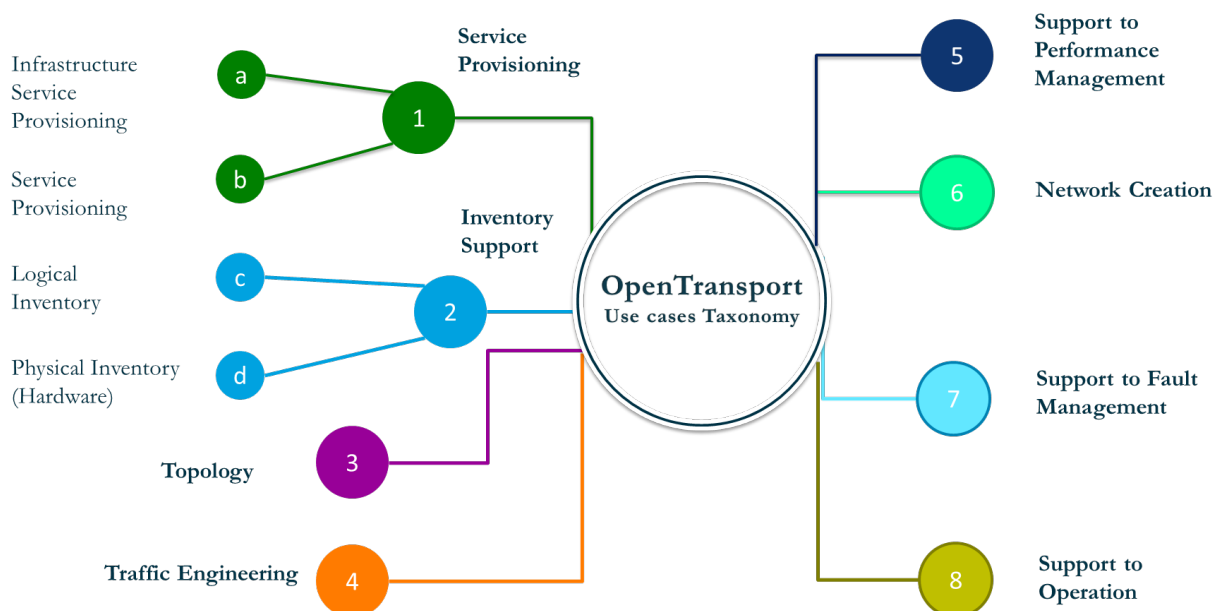


Figure 6 – Use cases taxonomy

We encourage other operators to join the project, sharing the work and methodology used, to push the industry in the same direction. Stronger and more agile standardization of the interfaces/data models is needed.

4.2.2 Data model standardization

Interface definition for disparate SDN scopes and technologies has blossomed in the past few years. A major SDN industry trend is the betting on the YANG language for defining data models and NETCONF or RESTCONF as preferred management protocols. A YANG model is a way to represent how an entity can be managed (e.g., which parameters are configurable, what is read-only information) and is the foundation of modern network programmability. Several YANG model types are considered:

- **Device YANG models** describe the configuration, state data, operations, and notifications of specific, device-centric technologies or features such as OSPF, BGP, or ISIS configuration. These will be used in domain controller SBIs for configuring NEs.
- **Network YANG models** describe the configuration, state data, operations, and notifications of abstract/vendor-agnostic representations of relations between multiple NEs. For example, this relational information can include topology models that show links between NEs. Connectivity services is another example, where models can represent a L3VPN, L2VPN (in the case of IP networks), and ODU or wavelength services in optical networks.

The standardization of data models and interfaces is taking place in different fora. While defining use cases, the proposal is to follow a “best of breed” approach and rely on several SDOs and industry consortiums:

- **IETF** – The YANG language, as well as its management protocols, is driven by IETF (www.ietf.org). In IP/MPLS networks, IETF-based topology, traffic engineering, and network service models are the most mature among the industry. The IETF is also defining YANG models for optical and microwave.
- **OpenConfig** – This forum (www.openconfig.net) has joined with several service providers to generate vendor-agnostic device descriptions. OpenConfig models are considered as base models for both IP and optical devices.
- **ONF** – The Open Networking Foundation (www.opennetworking.org) currently has the most mature optical NBI specification (known as T-API), as well as backhaul models for the SBI of MW deployments.

4.2.3 NBI standards

Communication between network controllers and OSSes, such as E2E service orchestrator, network planning tool, or resource inventory is performed via RESTCONF-based interfaces. RESTCONF is a HTTP-based protocol that provides a programmatic interface for accessing data defined in YANG [RFC 6020] (and [RFC7950] [RFC8342]) using data store concepts defined in the Network Configuration Protocol (NETCONF) [RFC 6241]. The main reason for choosing RESTCONF is it permits reuse of all tooling around the REST interface (today the industry norm).

4.2.3.1 IP network data models

Initial proposal for the IP network NBI specification is composed of the following YANG-based APIs (among others):

- L3 VPN Service NBI (draft-ietf-opsawg-l3sm-l3nm-03) [L3NM] – L3NM is used to manage the layer 3 VPN service provisioning within the IP/MPLS network. The SDN controller will derive configuration information to be sent to relevant network devices.
- L2 VPN Service NBI (draft-ietf-opsawg-l2nm-00) [L2NM] – Similarly, the L2NM model has been selected for managing L2 network VPNs.
- L1 Topology NBI ([RFC8345] and [RFC 8795]) – Represents the physical network, including routers, links, and relationship with the optical network.

- L2 Topology NBI (draft-ietf-i2rs-yang-l2-network-topology-11) [L2 TOPO] – Represents network Ethernet links, including nodes, termination points, and links.
- L3 Topology NBI ([RFC 8346]) – Represents the network IP links, including nodes (routers), termination points, and links.
- UNI Topology NBI (draft-ogondio-opsawg-uni-topology-01) [UNI TOPO] – Used to export potential service endpoints in IP topology.
- Traffic Engineering NBI ([RFC 8795]) – Permits the enforcement of traffic-steering flows by leveraging onto MPLS tunnels or SR paths.

4.2.3.2 Optical network data models

Due to its maturity and availability within the industry, the ONF Transport API [T-API] is the information model considered by most vendors as the optical domain controller NBI. Its recursive nature also permits use within various control hierarchy levels, including the interface between SDN domain controllers and the hierarchical controller, as well as between the latter and the OSS/orchestration layer.

T-API includes technology-specific information from each transport layer and is intended to augment the previously described service models. The transport layers covered by T-API are:

- DSR/Ethernet
- OTN/ODU
- Photonic media

However, for implementation simplicity of the target SDN architecture, we encourage ONF Transport API and IETF ACTN to converge. The Open Transport Group will foster initiatives toward this convergence, which would facilitate technology layer interaction.

4.2.3.3 Microwave network data models

Specific MW applications can work directly at the NBI with a non-abstracted exposure of the SBI models—taking advantage of SBI information model completeness, current standardized support, and validation to 1) implement specific functions, and 2) avoid the need for abstraction or translation. In specific case systems and applications that may benefit from abstraction, both IETF and ONF Transport API (T-API) specifications are under industry evaluation to assess maturity and possible data model limitations.

Important ETSI ISG activity began last year with the aim of testing all IETF data models needed for E2E service instantiation (creation, deletion, and modification) in a MW multivendor environment. The activity foresees disparate test sessions (Plugfest): first in Feb '19, second in July '20, and a possible third one still under planning. Within ONF standardization and evolution activities, additional POCs are under development, where these use case types (requiring abstraction toward higher layers) are progressing toward implementation and testing with several major MW vendors.

4.2.4 SBI standards

For all the technologies, the proposal includes the use of declarative configuration and model-driven management and operations. In that regard, NETCONF is considered the main protocol for device management operations. It's a network management protocol developed and standardized by IETF, with its latest version published in June 2011 ([RFC-6241]). NETCONF uses

data modeled in YANG and encoded in either XML or JSON. For open transport SDN, it's proposed to use YANG 1.1 [RFC 7950] as the main data models for devices, following a similar approach as for the NBIs.

The main modules for IP are those needed to configure disparate protocols (e.g., BGP, LLDP, LACP), modules to configure local routing (e.g., to include static routes), modules to retrieve the hardware of routers (chassis, cards, ports, fans, CPUs, et al.), and modules to configure VRFs and create VPNs.

Modules managing IP/MPLS routers will be based on OpenConfig models. They're vendor-neutral data models defined in YANG and cover actual operational needs from use cases and requirements from multiple operators.

In addition to NETCONF/YANG, two protocols (that also define the data model) are considered to support topology retrieval and TE:

- BGP-LS protocol to retrieve the layer 3 and SR topology (links, nodes) of the IP/MPLS networks
- PCEP to support TE and for reporting LSP statuses, instantiating PCE-initiated paths, and modifying PCE-delegated LSPs involving the NE from a stateful PCE (a function of SDN architecture)

For disaggregated optical equipment, NETCONF with YANG is also preferred. The main modules used for optical SDN operations are those needed to retrieve the transponder hardware (linecards, ports, fans, et al.) and to configure the optical transport (defining an optical device).

For MW devices (as for the NBI), both IETF and ONF are under evaluation by the industry to assess data model maturity and their possible limitations. The ONF-proposed YANG data model seems more mature and complete in terms of MW parameter support. The main modules needed are the core model, which describes the hardware of the MWa device (among others), and TR-532 model, which describes the RF parameters together with other technology-specific MW parameters and information.

5 OPEN NETWORKING

SDN solutions with standard interfaces enable operators to deploy NEs from various vendors in a more uniform manner. This advantage is crucial when considering migrating to disaggregated scenarios.

Network disaggregation is a concept that is becoming very relevant for the whole industry, including operators. Today telcos purchase NEs from system integrators who define the hardware solution (switch, microwave, router, or transponder), purchase the components from third parties, and carry out device integration as well as software development/ integration needed for NE functions.

However, the open networking movement with fora such as Open Compute Project (OCP), Telecom Infra Project (TIP), and now GSMA, proposes to disaggregate the NE ecosystem to multiple vendors. This means each vendor can work with interchangeable hardware and software solutions that work together in an NE.

The two main pieces in a disaggregated solution are the hardware system, or *white box*, and software, called *network operating system* (NOS), which support networking functionalities (L2, L3, etc.).

The white box is formed with components such as a chipset, memory, and pluggables. The white box design is available to third parties, so any manufacturer can obtain it to develop their NOS solution on top of it.

Compared to closed environments, open networking reduces operator entry barriers by permitting any company to build new network solutions faster, with better agility, and with the help and support from a higher number of contributors. Open networking also supports accelerated adoption of many key frameworks and software solutions. However, there are associated challenges.

Today system integrators have a substantial role in installation, integration, commissioning, and maintenance activities related to network equipment. For these the NOS has to be integrated with the telco's systems, meaning that new contributors are exposed to legacy-associated complexity. The SDN paves the way for easing such integration, as the NOS and SDN controller interfaces are standard and common to incumbent vendors.

The previous explanation is accurate for packet (switches and routers) and MW elements, but for optical systems there is an intermediate concept called partial disaggregation. Optical transport DWDM networks for telcos are deployed on a regional basis. They include all needed system elements: reconfigurable optical add-drop multiplexers (ROADMs), tunable filters (TFs), inline amplifiers (ILAs), wavelength multiplexers (W-MUXs), transponders, and the network management systems (NMS). A partially disaggregated optical network decouples the transponders from the line system, meaning they don't have to belong to the same vendor.

6 NETWORK INTELLIGENCE

Network intelligence aims to provide programmability capabilities along with an awareness of and ability to take autonomous, real-time actions on the current network state. It enables TE and automated service provisioning between disparate layers and vendor technologies. Such intelligence is enabled by the SDN controllers hosting real-time information related to the network state, control, and services.

6.1 Traffic Engineering

TE permits the enforcement of traffic steering flows by leveraging onto MPLS tunnels or segment routing paths. This lets operators increase efficiency by properly mapping traffic flows to available resources. It also improves network management—including troubleshooting—to overcome difficult failure situations. Increasingly complex network scenarios, such as large, single-domain environments, multi-domain, or multi-layer networks require algorithm use for efficiently computing E2E paths.

This complexity is driving the need for a dedicated SDN controller, which will perform path computations and can adapt to network changes. The PCE function used by the SDN controller can perform complex, constraint-based path calculations over a network graph

representation. Introduced by the PCE, centralized path computations improve the application of TE policies in MPLS and GMPLS networks by mitigating race conditions inherent of distributed systems.

Making a network predictable, TE optimizes usage and resilience, permitting operators to make better use of resources, provide more reliable traffic delivery, offer advanced services and SLAs, and avoid outages and planned maintenance.

6.2 In-Operation Network Planning

Current transport networks are statically configured and managed. Moreover, inventory and service information is only periodically updated without a well-defined classification of the resources and connections. As a result, long planning cycles are used when upgrading a network and preparing it for the next planning period. To guarantee a network can support forecasted traffic and deal with failure scenarios, spare capacity is usually installed well in advance, thus unnecessarily increasing CAPEX spend.

Thanks to information retrieval and programmability (automation) through the SDN controllers' APIs, a network can be reconfigured and reoptimized in real-time to respond to traffic changes. Hence, resource use can be improved and overall network performance increased. By having up-to-date information, planners can more accurately predict traffic usage and optimize network build-outs, thereby reducing money spent on infrastructure.

6.3 E2E Transport Service Programming

When operators consider designing and deploying new services, they often realize that the service definition is coupled with NE configuration. Configuration of network transport technologies (IP, optical, MW) are very different, which increases deployment complexity. Even overlay services are very difficult to deploy against traditional, vertically integrated management systems.

Thus, the aim of an open transport SDN is to have a clear, vendor- and operator-independent definition of services and network configurations. Operators can benefit from management systems or applications that can automate service deployment across multiple technologies, domains, and even companies through a common set of network APIs.

Once service definition is decoupled from network configurations by these APIs, coordination between service-related and transport-related control functions is required to enable the evolution of both. Toward this aim, a modular control approach for both services and transport/connectivity is easier to design and validate that considers cooperative interaction. Control solutions on either side can evolve independently—not only creating fewer risks, but also permitting independent and optimized migration.

6.4 Automation and Scheduling of Maintenance Operations

Due to lack of automation in current networks, many configuration tasks are done manually. During their execution, such human actions have a high probability of impacting network availability in a negative way—principally due to mistakes, inconsistencies, or configuration conflicts. Careful method of operation (MOP) planning and set maintenance activities helps minimize such risks, but they'll remain latent until a network is fully automated.

The possibility to automate maintenance operations or network changes on-demand is a quick win derived from the introduction of PCE. As a centralized control element with full network visibility, it's able to drain, reroute, or move traffic if some nodes or links aren't part of desired/optimal paths. This lets operators schedule maintenance tasks and move traffic during certain dates or time periods as desired.

In addition, the high level of SDN agility can enhance operation tools. Since inventory information might not be totally up-to-date—especially after an outage—it's necessary to provide a real-time view of a network and services running through it. SDN's ability to do this can help facilitate operational status analysis during or after an outage.

As another example, operation teams have to make installations, software and hardware upgrades, and reparations during maintenance windows. The agility provided by SDN can accelerate time-to-configure and time-to-repair, thereby shortening such timespans.

6.5 5G Network Slicing

Network slicing is a key technology for 5G—as defined by the Next Generation Mobile Networks Alliance (NGMN)—permits efficient resource sharing of a common infrastructure among disparate services. The concept foresees a number of logically independent slices, each comprising different network nodes and functions, which are interconnected in a given way and intended for a specific use case or service application.

Such slices will let network service providers overcome the great challenge of forthcoming 5G services. That is, how to support and operate various services having very distinct needs (i.e., eMBB, mMTC and uRLLC) on top of the same physical infrastructure, and in a way that they're created dynamically and transparently to users and to overall network orchestration.

The SDN transport target architecture presented herein is considered an essential enabler of future 5G network slicing automation in the transport domain. Through the hierarchical controller and underlying SDN domain controllers, operator orchestration will set up and monitor E2E 5G by requesting connectivity slices in the transport network with their requested SLAs.

7 CONCLUSIONS

The goal of the presented target SDN architecture is to achieve multi-layer and multi-vendor transport network programmability through the use of standardized interfaces and data models. Hierarchical architecture provides the adequate level of abstraction and scalability at each layer (NEs, SDN domain controllers, hierarchical controller) providing a standardized, lean, and agile interface with OSS/orchestration systems and achieving the desired business agility through full network automation.

A focus is to ensure native SDN support of all new node deployments, avoiding the use of ad hoc mediators toward NEs whenever possible. This approach is a pragmatic one, starting with per-vendor SDN controllers and focusing on specific use cases (i.e., L2VPN/L3VPN creation, 5G hard/soft slice creation, et al.) and moving toward multi-vendor SDN domain controllers.

As explained in section 4.2.1, the open transport SDN group is focusing on the prioritization, specification, standardization, validation, and deployment of SDN use cases to be agreed upon between operators.

The availability of an open and jointly built, multi-layer, vendor-agnostic transport SDN architecture (as presented herein) will be essential in achieving the required flexibility, automation, and business agility required from our networks going forward.

Our operator group encourage others to join and contribute toward the mission of defining and accelerating the standardization and implementation of required SDN interfaces and use cases needed for our transport networks.

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