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Review of Applicability of SDN in OTN

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Abstract— SDN shifted the perception of value from hardware to software. It has gained popularity in Data Center Networks and are also slowly rising in Telecom Network space. There is a significant value in applying SDN architecture in Optical Transport Network. It is important to understand that the Optical Transport Networks have specific characteristics. Hence the applicability of SDN underlines various specific considerations which are otherwise not applicable in other Ethernet based or L2/L3 networks.

The objective of this review paper is to specifically review how Software-defined-networking (SDN) can help in transforming Optical Transport Networks. Section 1 discusses the Optical Transport Networks deployment in general. It outlines the definition of the OTN and then presents the overview of OTN in present day network. Section 2 lists the benefits of SDN, specifically to Optical Transport Network. These benefits take into account not only the traditional OTN, but also the modern OTN with enhanced features. Section 3 presents an illustrative review of important considerations which clearly outlines how applicability of SDN in OTN differs from common Layer2/3 networks. The final section 4, takes a summary view of further research in SDN specifically to help with more inclusion of OTN and how various SDN initiatives are focusing on Optical Transport Network integrations.

Keywords— SDN (Software defined network), OTN (Optical Transport Network), OpenROADM, Open Flow, Layer 0

I. INTRODUCTION AND BACKGROUND

As per ITU-T definition, Optical Transport Networks are defined as "a set of Optical Network Elements (ONE) connected by optical fiber links, able to provide functionality of transport, multiplexing, switching, management, supervision and survivability of optical channels carrying client signals".

OTN is widely recognized as the primary Transport Technology for multi-service, packet-optical networks. It is not an overstatement to say that OTN has gained a ubiquitous status in modern-world Transport network. Fig1 indicates the tremendous growth potential for OTN in coming years.

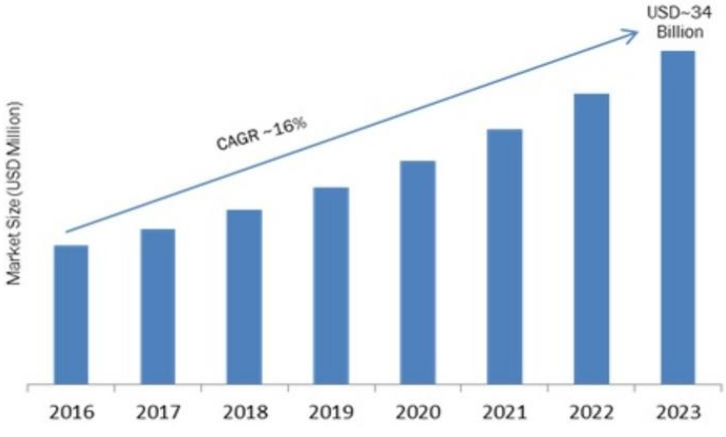

Fig1: Global OTN Forecast (Coursey : OTN Market Research Report - Global Forecast to 2023)

Initial OTN architectures were built to support long-distance voice traffic. A high standard of reliability was built in into these networks. There was no expectation to deal with highly dynamic capacity demands from earlier architectures of OTN. Traffic was predictable with spikes at certain times of the day or the year. These underlying Layer 1 and Layer 0 networks have often been considered "fixed" in the sense that, their primary responsibility is to act as a point-to-point underlay, providing the necessary capacity between Ethernet/IP domains.

The growth in traffic volumes, dynamic traffic profiles and types of applications, requires service providers to give careful consideration to the optical transport backbone. Service providers are now expecting agility and programmability from what was previously considered "fixed" layer 0/. SDN (Software Defined Networking) can offer this flexibility, agility, programmability to the OTN.

The primary focus of SDN within the industry (as well as academia) has centered around Layer 2, Layer 3 and above. [4]. Technology for SDN optical networks is not yet as advanced as SDN for the data center. But there is a rising consensus that Optical networks need the capabilities of SDN to respond to market demands for dynamic bandwidth provisioning and lower operation costs. The next section reviews the benefits that OTN can obtain by introduction of SDN based architecture.

II. HOW OTN CAN BENEFIT FROM SDN

At the outset, following benefits are obvious from the applying SDN paradigm to the OTN:

- The ability to scale network bandwidth up or down rapidly by facilitating deployment of optical bandwidth and IP resources
- Added resource utilization efficiency by optimizing the path taken through the multi-layer network
- Lower Opex by automating operations across the network layers, eliminating device-by-device configuration and coordinating provisioning functions
- SDN's centralized view of the network enables it to evaluate individual layers of the network to determine where and how to best send traffic.

With the introduction of digital signal processing in the new generation of coherent transceivers, it is now possible to design flexible hardware that will support trade-offs between parameters such as optical reach, bit rate, and spectral efficiency under software control [10]. Simillarly, new advances in optical technology can allow network operators to program the optical layer. These technologies open the gate for SDN in the optical transport layer.

A few examples are:

- Software-defined optical port speeds, protocols, and wavelengths
- Advanced modulation and detection schemes, especially at 100 Gb/s and higher speeds
- A flexible wavelength grid rather than a fixed 50 GHz grid
- Flexible wavelength routing via dynamic ROADMs
- OTN grooming and switching

Employing these programming capabilities, the optical transport layer can be abstracted to a set of shared, common resources that can be used dynamically and on-demand. Using a flexible optical layer, SDN can evolve from its initial packet applications to support more generalized switching and transport applications[8]. One example of this is Using Network slicing to realize Optical VPN.

The ability for a service provider to have a homogeneous, uniform, consistent view of the entire network is paramount. Large Tier-1 networks are inherently multi-vendor [4]. An SDN controller can also provide for coordinating services across multiple network layers (e.g., packet, TDM, and optical) and among non-interoperable technologies (e.g., proprietary embedded control plane or incompatible features) in the same layer, capitalizing on network abstractions at the various layers and hardware independent control. [8]

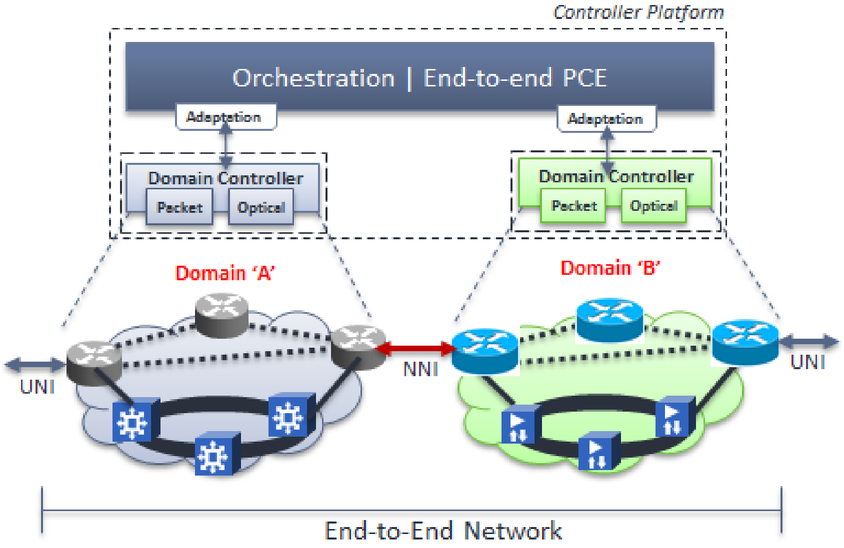

Fig2. Multi-Layer and Multi-Domain Coordination (Courtsey: [4])

The mediation between control plane segments and layer boundaries (e.g., between packet and optical layers) is often a manual process that software defined networking (SDN) [9] could automate. Now that some of the possibilities and benefits of SDN are listed, its important to review key considerations before deciding to implement SDN to separate Data and Control plane. As can be seen from next section, not every situation is best handled only by separating Data and Control plane.

As described in [11], The benefits of using SDN to telecoms service providers are profound. These benefits can all be passed on to the customer. Replacing proprietary pieces of hardware with standardized servers and networking brings the agility to deliver new services dynamically while significantly reducing CAPEX and OPEX costs. As illustrated in [12] with a mathematical expression, SDN improves the efficiency and thus lowers the net OPEX of the optical network.

III. KEY CONSIDERATIONS WHILE SEPARATING DATA AND CONTROL PLANE FOR OTN

One of the central tenets of SDN is data and control plane separation. The idea is for equipment vendors to provide programmable interfaces allowing routing, QoS decisions to be made outside the device. One of the primary reasons is to enable faster innovation (not locked to vendor development cycle). While these remain true, some of these drivers slightly differ when it comes to optical transport networks. [4]

Control plane implementations for optical networks are more complex since they must account for physical constraints including optical signal reachability, bandwidth availability and granularity, light path routing, and light path reconfiguration speed. Moreover, to support transport networks with multiple administrative and technology segments, communication and interoperability between control planes is required. [8]

Although standards exist for data plane interoperability, Layer 1 data plane interop has challenges (as opposed to Ethernet/IP). Every vendor has proprietary frame formats (in the interior network domain/NNI). In addition, the granularity of grooming functions differ, making it non-optimal to define generic, vendor-agnostic models for timeslots, connections, multiplexing identifiers, topology discovery and other traffic carrying entities. This problem is compounded further for Layer 0 (optical domain) due to proprietary modulation/encoding and Forward Error Correction (FEC) schemes. Protection/restoration add additional complexities; given the stringent requirements on protection (typically sub-50ms), a traffic outage like a fiber cut can impact tens/hundreds of gigabits. Hence, it is best for performance reasons if protection/restoration functions are left to the embedded control plane. [4]

Layer 2 and Layer 3 networks have traditionally been interoperable both in data (E.g.: IP/MPLS) and control planes (E.g.: BGP, OSPF). As far as Layer 1/Layer 0 optical networks are concerned, data plane interoperability is in theory possible; ITU specifications [5] allows for multi-vendor digital and optical interface interworking. L1/L0 optical control plane interop, however, has a lot of challenges. GMPLS control plane implementations across optical vendors seldom interoperate; Alternate standardization efforts haven't seen wide adoption [6][7]

For Ethernet, IP, and multiprotocol label switching (MPLS) networks, OpenFlow is one protocol that could provide a standardized interface to the hardware, but does not cover circuit or wavelength-based equipment. [8]

It should be noted that traditional optical networks have been managed using an element management system (EMS/NMS) that requires network operators to design circuits and consequently drive the configuration of network elements.[8].

A common, vendor-independent service definitions can be established for typical L1/L0 digital and optical services. This would include common information models and management interface specifications to cover the full spectrum of FCAPS and OAM&P. This would ensure that multi-vendor integration becomes easier and helps with interop testing. Initiatives such as OpenROADM are examples of work in this area.

As the industry moves beyond demonstrations to deployment and operationalization, it is important to try to understand not only the virtual world, but the physical world of optical networks. For SDN control of the OTN to succeed, the underlay (layer 0 and layer 1) transport structure must be designed in a way that allows its attributes to be controlled via software. [2]

There have been demonstrations that showcase activating a 100 Gb/s wavelength on demand, selecting its color, configuring its launch power and setting other analog optical parameters. They may also include dynamically operating reconfigurable optical add-drop multiplexors (ROADMs) along the path to switch these new wavelength colors across the transport network. But it needs to be verified if these demonstrations had known limits, e.g.

- The 100-Gb/s line card that hosts the activated wavelength already installed in the chassis and connected to the fiber but inactive
- The card pulled from spares inventory or ordered from the vendor's inventory and then installed (a manual human process

A centralized control plane may not offer the best design in all cases. It may impose performance and scaling limitations compared to distributed control networks. Performance can be improved by adding processing power and precomputing protection paths, but getting failure notifications and effecting dynamic reroute will be slower than with a distributed control plane. [8]

As it goes with any emerging technology, the above considerations should not be looked at as the bottlenecks or road-block. In fact these considerations give right insight and direction on how the fitment of SDN within OTN will evolve. The next section touches upon various forward looking initiatives that will help in promoting and/or standardizing SDN in Optical Transport Networks.

IV. INITIATIVES WHICH COULD HELP IN STANDARDIZING SDN IN OTN

Recently, the Open Networking Foundation (ONF) announced a partnership that boosts software-defined networking in optical transport networks. (ONF Partnership Aims SDN at Optical Transport Networks. [1]) The consortium last week announced a collaborative partnership between its Open Disaggregated Transport Network (ODTN) project and the Telecom Infra Project (TIP's) Open Optical & Packet Transport (OOPT) group.

The Open and Disaggregated Transport Network (ODTN) project is an initiative to build datacenter interconnects using disaggregated optical equipment, open and common standards, and open source software. The Open Optical & Packet Transport group works on the definition of open technologies, architectures and interfaces in optical and IP Networking.

The new release 1.5 of the ONF OpenFlow protocol will have extensions for transport networks. [3] These are a set of recommended extensions to the OpenFlow-Switch protocol to support the requirements for control of optical transport networks and equipment.

One aspect which would significantly benefit the optical transport community is standardization of L1/L0 services. Hence initiatives such as OpenROADM ("Multi-Source Agreement www.openroadm.org", 2016) are quite useful. There are four models for Device/Network API (including OpenROADM), which are as mentioned below.

A. IETF Traffic Engineering Architecture and Signaling (TEAS) TE Topology

The main focus of this API, which already has several customers, is IP over optical transport. It uses SDN to guide network traffic, improving resource utilization and helping to meet network quality of service requirements.

B. ONF Transport API

Initiated at ONF in 2014, this standard northbound interface supports both high-level intent-based services and detailed technology-specific services. It's focused primarily on carrier transport networks and is currently at the heart of several major RFIs for SDN solutions. Ongoing tests and demonstrations include the OIF SDN Transport-API Interoperability Test 2018 based on ONF T-API 2.0, exploring the basis for real-time orchestration of on-demand connectivity setup, control, and monitoring across diverse multi-layer, multi-vendor, multi-domain carrier networks.

C. OpenConfig

Active in some of the largest DCI networks and used by leading Web 2.0 providers, this direct device API is applied to the configuration of IP, Ethernet, and streaming telemetry devices – meaning data can be continually and automatically streamed from devices for enhanced network monitoring. Operators can subscribe to the specific data items they need using OpenConfig data models as the common interface. For many, it's a key element of network disaggregation.

D. OpenROADM

Along with OpenConfig, this is one of the two leading device APIs right now and, while OpenConfig is favored by the cloud community, OpenROADM is gaining traction in the carrier community. Driven by AT&T and supported by a small group of vendors, this interface is seen by many as a path to full network disaggregation.

V. CONCLUSIONS

SDN can offer significant benefits to existing and modern OTN. SDN opens up possibilities which were not possible in current OTN. The applicability of SDN and its various aspects, such as control plane centralization, programmability needs specific consideration for OTN. There are focused efforts and work going on in the area of SDN which help in promoting SDN further in OTN.

ABBREVIATIONS AND ACRONYMS

API	Application Programming Interface
CAPEX	Capital-Expenditure
EMS/NMS	Element Management System/Network Management System
MPLS	Multi-protocol Label Switching
ONF	Open Network Foundation
ONE	Optical Network Element
OPEX	Operating Expenditure
OTN	Optical Transport Network
RAN	Radio Access Network
ROADM	Reconfigurable Optical Add-Drop Multiplexer
SDN	Software Defined Network

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