Design Approach to Solve Challenges in Applying SDN To OTN

VISHAL VASANT DESHPANDE [#1], Dr. Shripad P. Mohani [*2]
Dept. of E&TC, GCOE-J, NMU
vish_d@outlook.com
shripad.mohani@gcoej.ac.in

***Abstract*— Optical Transport Network (OTN) has significant growth potential as de-factor transport network technology. Traffic patterns are becoming unpredictable and also there is an expectation to dynamically configure new services. But OTN lacks flexibility and programmability. Software Defined Networking (SDN) has shown its benefits in Datacentre networks (DCN) by bringing programmability. This paper initially presents an analysis of the challenges faced while applying SDN to OTN. This multi-dimensional analysis covers aspects ranging from physical constraints to multi-domain management to standards and protocols. The benefits of applying SDN to OTN are huge and hence the challenges need to be resolved. Researchers are working with a high focus on SDON (Software Defined Optical Network) to transform OTN into dynamic and programmable network architecture. This paper further illustrates possible solutions to key challenges, which can enable applying SDN to OTN. The research critically looks at present SDN and OTN interface and suggests innovative improvements in SDN as well as OTN side. As a unique contribution, the paper also provides a recommended design approach that can be used while applying SDN to OTN. This recommended approach consists of sequence of steps, indicates the choices to be selected and highlights the reasons for selection.**

***Keywords*—–SDN (Software Defined Network), OTN (Optical Transport Network), OF (Open flow protocol), ROADM (Reconfigurable Add-drop Multiplexor), DCN (Data Centre Network), EON (elastic optical network)**

I. Introduction

OTN has gained ubiquitous presence in transport networks. For multi-service packet-optical networks, OTN is widely recognized as the primary Transport Technology. Existing OTN architectures support long-distance voice traffic. They were built specifically for traffic that was mostly predictable, except spikes at certain busy hours. Now, growth in traffic volumes along-with changing traffic profiles, requires service providers to reconsider this optical transport backbone architecture. Modern applications require flexibility and quick reallocation of resources. Present OTN deployments takes care of dealing with the enormous amount of information. This brings challenges for the network administrators (from service provider) in terms of arranging management and control of OTN. This changing expectation is causing pressure on optical transport networks.

SDN offers an alternate option to current network administration technology. At a high level, SDN is a new approach to programming the data networks switches that has scalable and centralized network-control architecture. Presently, the SDN is being utilized to control the electric domain network (like LAN, WAN) and in some cases Wireless networks. Thus, SDN shifted the perception of value from hardware layer to centralized control software. Researchers and experts noted that it is beneficial to combine management and control of many layers [16]. In year 2014, at the Interop & Tech Field Day, Avaya exhibited software-defined networking using OpenStack and showed network automation [23]. Since then, it is gaining popularity in Data Centre Networks (DCN) i.e. packet switched network.

In theory, it is expected that SDN can help in transforming OTN. There is a possibility to bring value for service provider and end-use by applying SDN architecture to OTN. While SDN is introduced for packet switched Data Centre network, its application to circuit-switch OTN is not straightforward. This paper is primarily focused around applicability of SDN architecture for OTN and achieving the benefits SDN has to offer. The paper combines areas such as analysis of problem, evaluating alternative solutions and then recommending a design to solve the problem, so as to apply SDN to OTN.

The paper is organized in sections. Section I gives brief introduction of problem area. It explains the importance of OTN and the challenges faced by OTN. It also mentions how SDN has helped other network technologies (non-optical) to bring flexibility in network. Section II has literature review from other research works encompassing SDN in general (any type of network), as well as advances in optical transport network. Section III describes the problem in more details by enumerating key challenges while applying SDN to OTN. Section IV briefly mentions benefits that applying SDN can bring to OTN. These benefits have motivated to undertake this research work. Section V presents the contributions of this paper. Firstly, it describes possible solutions to these challenges. Then it recommends a unique solution design approach that can help solving the problems faced by OTN while applying SDN architecture. Lastly, conclusion section gives summary and completes the paper

II. Literature review

Before applying SDN to OTN, it is important to get support of Service providers and consider their point of view. The literatures [13] [14] [4] take a thorough view of Tier-1 service provider expectations and challenges. In [13] presented service provider perspective for those planning to carry out such deployments in the core network. It further explains present state as well as future challenges in combining SDN with OTN. It focuses on efficient dynamic resources assignment possibilities with software defined elastic optical networks (SD-EONs). It tries to mention SDN benefits in light path establishment. Similar study on making the optical network 'elastic' (dynamic) is carried out by [14]. It proposes "utilizing a reproduction system". This refers to a strategy to use centralized view of SDN, to control optical power profile for expansion of limit. The study was able to expand existing limits by additional 12% (capacity gain without new devices).

One of the interesting considerations while applying SDN to OTN is about multi-domain, multi-layer networks. Most service provider environments have optical networks along-side of electrical networks. If SDN can be shown to manage all these domains and all the layers, it will have higher acceptance. In article [15] the significance of SDN for network control and management is discussed by describing SDN architecture with three independent planes. This SDN based layered view involving optical networks has the benefits and also issues, during execution for SDN in optical systems. Authors of [16] presented network architectures with multi-domain networks and explains comparison of solutions involving SDN. This also outlines difficulty in its implementation of multi-layer SDN architecture for both, inter and intra-DC SDNs. Literature [17] has made a useful proposal for SDN applicability. Its approach is to maintain existing MPLS routers managing packet network and superimpose it with SDN control plane. The superimposing SDN enables IP-optical cooperation. This increases (at least in theory) possibility to enhance network functions without hurting existing network reliability. Santos presented [18] hierarchical as well as federated architecture for SDN controllers deployed in the optical domain. In hierarchical option, small sub-network controllers are managed by senior upper controller. Naturally, this adds to increasing operation duration. Another architecture option has federation of multiple sub-network which oversees partial network. This has better results till higher traffic loads deteriorates routing efficiency.

Researchers with expertise in cloud (and having bias towards cloud architecture) have been suggesting to use virtualization approach to try out SDN with virtualized OTN. The article [4] presented technical paper based on prior experience with virtual OTN Switch (OTS-v) deployment. Authors of [19] introduced applicability solution with virtual optical network control. This is based on SDN applications utilizing context-aware network wide strategies which are implemented as policy flow. The simulation for this solution contains assisted local policy mechanism (as in Transport SDN). Another approach in [20] focuses on hierarchical OAM layers and using NETCONF protocol (as OAM protocol). This API driven abstraction has OAM Handler which gets multi-level OAM information from filtered view of OAM messages at different layers. Another article [21] studies the virtual optical network to investigate its survivability in embedded SDN domain. Results from Simulation exercise indicate enhanced model in multi-domain with superior execution. In-depth analysis in [22] explains the hardware infrastructure and how network virtualization layers can appear. It looks at SDN as Network OS and has discussion about southbound and northbound application programming interfaces (APIs) to SDN.

III. Key challenges in applying SDN to OTN

One of the central tenets of SDN is data and control plane separation. SDN controller forms a control-plane layer in DCN. But control plane implementations for optical networks are much more complex compared to packet network domain. As seen in Figure 1, the existing packet network (e.g. DCN) does not have sufficient knowledge or visibility into optical layer components and requires an optical network controller to work with optical components.

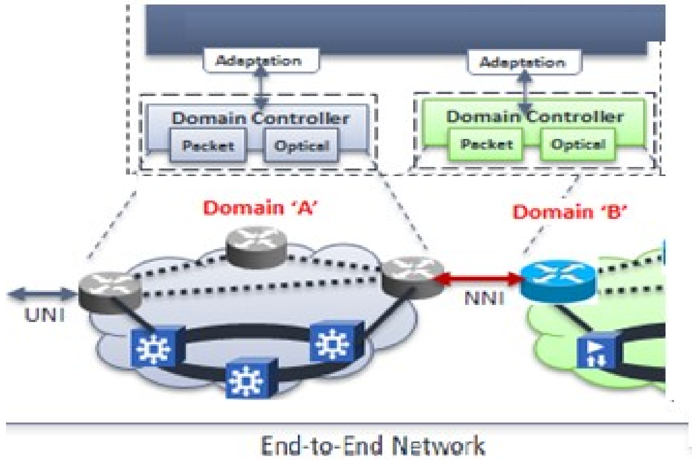

Figure 1: Multi-Layer and Multi-Domain Coordination [4].

The reason behind the need of separation of data-plane and control-plane is that, hardware vendors can provide programmable interfaces to allow routing, while decisions related to QoS to be made outside this hardware layer. One of the primary reasons is to enable faster innovation (not locked to vendor development cycle). Some of these drivers differ in case of optical transport networks. [4]. Implementation of Optical Control plane is comparatively more complex. It has to account for optical characteristics and physical constraints. Control plane has to be aware of signal reachability aspects and continuous wavelength availability or bandwidth granularity. Moreover, to support transport networks with multiple administrative and technology segments, communication and interoperability between control planes is required. [8]

In data plane, standards exist for interoperability but still, Layer 1 data plane interoperability has challenges in optical domain. Vendors chose to have proprietary frame formats (e.g. between their own devices or at node-network integration points). 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]

Traditionally, L2/L3 networks have 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 interoperations have many challenges. Implementations across optical vendors rarely interoperate and alternate standardization efforts haven't seen wide adoption [6][7]

For Ethernet 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] Traditionally, Optical networks have been using Network Management Systems (NMS) to manage and monitor optical network domains. The network operator uses the vendor specific NMS to design a circuit and then configures various hardware elements as required by design [8]. Thus, these interfaces are neither standardized nor open to connect.

A common, vendor-independent service definitions is required to be established for common L1/L0 digital and optical services. This will need to 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 interoperability. In the network layer, Optical network uses dedicated network management systems (NMS) for configuring and monitoring. Integrating these legacy management systems with SDN controllers requires defining standardized interfaces and protocols, to exchange control and management information. Ensuring seamless interoperability and coexistence between legacy management systems and SDN-based control architectures can be challenging due to differences in operational paradigms and protocol semantics.

As the industry moves from initial research to demonstrations, it is important to understand the physical nature 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]. At present physical optical attributes are not controllable through software commands. Another issue relates to granularity. Optical networks typically operate at a very high level of granularity, with wavelengths being the basic unit of transport. SDN, on the other hand, often operates at a finer granularity, such as individual packets or flows. Bridging this gap in granularity requires special care in design. This granularity mismatch demands translation of high-level SDN control commands into low-level optical actions. It requires complicated mapping and translation mechanisms adding to network complexity and overhead.

There have been demonstrations that showcase activating a 100 Gb/s wavelength on demand. It is possible to select its colour (i.e. lambda), modify launch power or configure analogue parameters in optical domain. Such demonstration setup can include advanced ROADM (reconfiguration add-drop-mux) in the path. Such devices are capable of dynamically switching various wavelengths (colors) to allow some flexibility of transporting them in otherwise static transport path. Further verification of such demonstration is required to check if:

(a) The 100-Gb/s line card that hosts the activated wavelength already installed in the chassis and connected to the fibre but inactive

(b) 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] In such situations, all SDN controllers must gain visibility and should have control access to multiple network layers, so as to coordinate configurations or restorations.

These multiple challenges are causing limitations to network operators in applying SDN to OTN and expand the features and functionalities of OTN to embrace growth. The researchers are continuously working on these problems, to find possible ways and alternatives to enhance OTN and allow network flexibility. The next section discusses benefits of applying SDN to OTN, which also forms the motivation for research work for solving these problems.

IV. Benefits of applying SDN to OTN

As seen in previous section, applying SDN architectural model to OTN poses numerous challenges and researchers are trying to find solutions to these problems. The reason behind it is, the benefit that SDN can offer to present-day ‘static’ OTN. Following list has obviously apparent benefits from 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.

Additionally, there are more possibilities in future networks. The introduction of digital signal processing in the new generation of coherent transceivers, has now made possible to design flexible hardware. Such hardware will support trade-offs between optical parameters such as optical reach, bit rate, and spectral efficiency under software control [10]. Similarly, new advances in optical technology can allow network operators to program the optical layer for example 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). SDN can automate the manual mediation process, between control plane segments and layer boundaries (e.g., between packet and optical layers).

In summary, the benefits are lowering costs, increased revenue, new feature possibilities, efficient operations and ease of management. Each of these points underline the necessity to find solutions to the challenges mentioned in previous section. Next section provides more information about possible solutions.

V. POSSIBLE SOLUTIONS AND DESIGN CONSIDERATIONS

Once the abovementioned challenges are addressed, SDN has the potential to revolutionize the management and control of optical transport networks (OTN). This would create a more agile, responsive, and cost-effective infrastructure. This section proposes solutions and alternate approach to overcome the challenges.

A. List of possible solutions

It can be seen that physical constraints and optical characteristics form a major cause of concern in applying SDN to OTN. This can be solved by implementing an abstraction layer that hides the complexity of the physical layer from the SDN controller, and allows easier integration and management. OpenFlow protocol v1.5 comes with Optical extensions [24]. This 'optical aware' extension of the protocol promises better handling of optical characteristics and physical parameters such as lambda, bit rate, dispersion. Using OFv1.5 gives another advantage. It can lead to development of standardized optical interfaces for interoperability among diverse optical equipment vendors.

Another set of challenges relate to management of multi-layer or multi-domain environment. Clearly, the strategy can not be force-fit SDN controller (that manages DCN) to manage optical domains. Hence existing SDN controller will need to upgrade itself to become 'multi-domain aware'. It should be able to 'discover' if the granularity of underlaying network is packet level or wavelength level and accordingly issue commands. This revamp is under research and may take some time. Meanwhile, as a temporary solution, SDN controller can co-ordinate with existing optical control layer to perform actions specific to optical domain. This solution has some overhead (interaction between SDN controller and optical domain controller) in short term, but it is one step forward in managing multiple domains with SDN controller.

Changes on OTN side are also mandatory to achieve this applicability. Present Optical hardware is quite monolithic and vertically integrated. The control-plane and data-plane is almost inseparable. This was by-design in traditional network for achieving better performance and tighter control. This has to undergo change. The first and foremost change required in OTN is separating control-plane from the data-plane (or forwarding-plane). We recommend this as an important design consideration for any SDON (Software defined optical network).

Another solution approach combines important aspects from cloud-world and software-world. Virtualization of hardware components, combined with modelling of OTN components and interfaces allows API based control of such virtualized network model. Such solution can bring tremendous amount for flexibility without needing much changes on SDN controller side. The effort and time required to standardize models and interfaces will influence the success for this solution.

B. Recommended approach to Solution Design

Based on previous design experiences, literature reviewed and learnings from failed experimental trials, the author has come up with a recommended solution design approach while applying SDN to OTN. Other researchers are advised to use these steps in same sequence. Moreover, they can rely on the choices recommended (e.g. OF version) in their network design to apply SDN for their OTN deployments. These design steps will help other researchers to come up with a design approach overcoming the complex challenges while designing optical networks with SDN.

1) The first and foremost step in the design is, to separate out optical control plane and Data plane from current optical network elements. Present day optical network elements do not allow easy separation of data and control plane responsibilities. Hence the design approach need to carefully achieve this separation. After separation of data-plane, it is advisable to:

- Retain all the optical characteristics (like dispersion, SNR) at data plane level
- Use existing Network management systems (NMS) to manage these physical layer configurations

There is a design presented that successfully separates control plane and data plane in an all-optical network [25]. The design can be used as an illustrative example (or a reference implementation) of how to separate data-plane carefully from control-plane. The design in [25] allows key SDN concepts to be successfully applied to all-optical transport ring network and bring software driven configurability to optical domain. This should also give confidence to readers that the approach and design steps mentioned in this section, are not theoretical, but have also been tried practically with proven results.

2) Existing SDN controller that works with DCN, will not work with Optical network as it is. Hence it needs to be enhanced to be able to communicate with this optical domain control plane. This includes adding features like command translation, making controller aware of additional data-types like lambda, integration points to access to capacity DB etc. Making these changes to existing SDN controller, allows it to adapt to optical domain and 'speak' language of optical network elements.

3) The first two design steps result in separated data and control plane with responsibilities divided. Now, in order to realize SDN model, it is required to allow software driven control. Hence the author suggests to virtualize the optical domain control plane and enable it to publish APIs related to optical control functionality. These APIs can be invoked by SDN controller to achieve programmability through software commands.

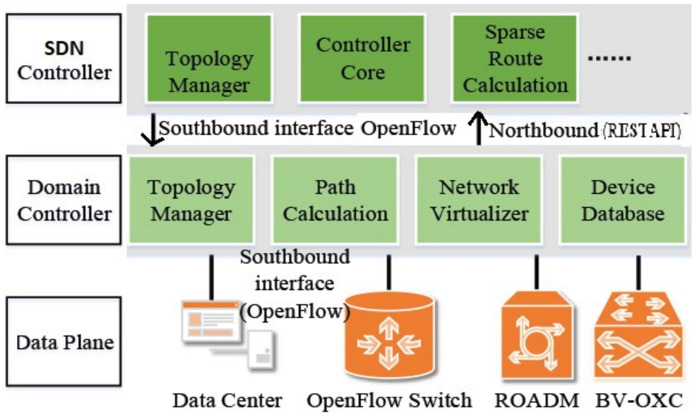

Figure 2: Design Approach to Apply SDN to OTN

4) Integrate the upgraded SDN controller with virtualized & programmable optical domain control plane. Care must be taken to ensure that upgraded SDN controller or the optical domain control covers all the required functionality.

Caution: There is an alternate design approach to create an agent instead of upgrading SDN controller or virtualizing optical control-plane. The author does not recommend such design for two reasons. First, it adds another layer. Second, it takes different direction from having SDN controller manage the multi-domain network in future.

5) Use standard Interfaces for communication:

- the author recommends using OF1.5 with optical extension for Control plane to data plane communication
- Optical domain control-plane can use NETCONF to communicate with SDN controller. It may also publish REST-API for its programmability invoked by SDN controller.
- Avoid any direct communication between SDN controller and optical data-plane. If in future, SDN controller becomes more advanced and optical-feature-rich, the Optical-control-plane can be removed. In this case, SDN controller will communicate with optical-data-plane.

VI. Conclusions

SDN is proven to be a workable solution to bring programmability in packet-switched networks like DCN. OTN is circuit switched. Moreover, it has special physical characteristics like tight coupling between its control-plane and data plane, granularity level different from packet networks. These differences pose challenges while applying SDN and demand special consideration. Hence it can be concluded that SDN can not be applied to OTN in a straight-forward way.

SDN can bring many benefits to OTN and can make OTN flexible and adaptable to the changing requirements. Researchers, Industry experts and Standard bodies are constantly trying to solve these difficulties or challenges. It is clear that work is needed on SDN side as well as OTN side to be able to apply SDN to OTN. OpenFlow protocol v1.5 with optical extension gave relief-news by extending OF for optical network. Virtualization plus model-based standardization of OTN (not yet proven) appears promising direction to enable programmability. Some hardware manufactures are trying to bring flexibility in Optical hardware. So, it is possible to solve these technology-challenges and apply SDN to OTN.

In the end, a recommended design approach gives sequence of steps, mentions reasons for choices and emphasizes the use of standards to design a programmable OTN with SDN controller. This design approach can help other researchers to reduce possibility of failures and guide them in their designs.

Acknowledgment

The author wishes to thank all article-authors mentioned in the References section for their efforts and for publishing their research articles.

REFERENCES

[1] David Ramel, "ONF Partnership Aims SDN at Optical Transport Networks", April 2019.

[2] Mike Capuano, "Let's Get Real About SDN for Optical Networks"

[3] Dr. Andreas Iselt, "SDN FOR OPTICAL AND TRANSPORT NETWORKS"

[4] Abhinava Sadasivarao, Dharmendra Naik, Chris Liou, Sharfuddin Syed and Anurag Sharma, "Demystifying SDN for Optical Transport Networks: Real-World Deployments and Insights"

[5] ITU-T, G.709: Interfaces for Optical Transport Network, Std., Feb 2012.

[6] OIF, External Network-Network Interface (E-NNI) Signaling Specification, Std.

[7] User Network Interface (UNI) Signaling Specification, Std.

[8] Steven Gringeri, Nabil Bitar, and Tiejun J. Xia, "Extending Software Defined Network Principles to Include Optical Transport"

[9] G. Goth, "Software-Defined Networking Could Shake Up More than Packets," IEEE Internet Computing, vol. 15

[10] K. Roberts and C. Laperle, "Flexible Transceivers," in European Conference and Exhibition on Optical Communication, (Optica Publishing Group, 2012, paper We.3.A.3)

[11] Vishal Deshpande, "SDN in Telecom Network", Apr 2019, International Journal of Advanced Research in Computer Science and Software Engineering 3 (4), April- 2019, pp. 1-6

[12] Laxmi Sharma et. al., "Software defined networking for optical networks"

[13] Amazonas, José Roberto de Almeida, et al. (2016). Technical challenges and deployment perspectives of SDN based elastic optical networks. In Transparent Optical Networks (ICTON), 18th International Conference IEEE

[14] Magalhães, Eduardo, et al., (2017). SDN control of optical nodes in metro networks for high-capacity inter-datacenter links. Optics Communications, p: 173–180.

[15] Routray, Sudhir K., et al. (2016), Software defined networking for optical networks. In Distributed Computing, VLSI, Electrical Circuits and Robotics (DISCOVER), IEEE.

[16] Kantor, Mirosław, et al., (2019). A survey on multi-layer IP and Optical Software-Defined Networks, Computer Networks

[17] Blendin, Jeremias, et al. (2016). Enabling efficient multi-layer repair in elastic optical networks by gradually superimposing SDN. In Network and Service Management (CNSM), 12th International Conference. IEEE.

[18] Santos, João, (2016). Scalable design of SDN controllers for optical networks using federation-based architectures. In Networks and Optical Communications (NOC), 21st European Conference. IEEE.

[19] De Siqueira, Marcos Antonio, et al., (2015). Providing optical network as a service with policy-based transport SDN. Journal of Network and Systems Management, 23(2): p. 360-373.

[20] Paolucci, Francesco, et al. (2015). Hierarchical OAM infrastructure for proactive control of SDN-based elastic optical networks. In Global Communications Conference (GLOBECOM), IEEE

[21] Ma, Jiachen., et al. (2015). Virtual optical network embedding with SDN architecture based on memetic algorithm. In Computer Science and Network Technology (ICCSNT), 4th International Conference on IEEE

[22] Kreutz, D., et al., (2015). Software-defined networking: A comprehensive survey. Proceedings of the IEEE, vol. 103, no. 1, pp. 14-76, Jan. 2015

[23] Tech Field Day 2014, recording at https://techfieldday.com/video/avaya-software-defined-data-center/

[24] Yongli Zhao, Yuqiao Wang, Wei Wang and Xiaosong Yu, "Software-Defined Optical Networking (SDON): Principles and Applications", Intech Open Science @2017, under Creative Commons Attribution License

[25] Vishal Deshpande, Dr. Mohani, "Achieving Path Reversal In Otn By Control Plane Programmability, Global Journal of Computer Science and Technology, volume 24, issue G-1, pp 27–36