Grenze International Journal of Engineering and Technology, June Issue

Innovative All Optical Transport Network Design by Control Plane Separation to Demonstrate SDN-like Path Programmability

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***Abstract*— Software Defined Network (SDN) promises to bring agility and programmability in the network using software. SDN has been successfully used in IP networks deployments. Applying SDN to all-optical transport networks has some challenges. Both, SDN side and OTN side, needs mutual changes to adapt to each other. This paper presents an innovative design of all-optical transport network. This design encompasses key SDN concepts such as control plane and data-plane separation, path decision based on central view of network, software based programmability. The design was thoroughly tested for scenarios of changing path dynamically. Additionally, the design helps in realizing a scenario of dynamically configuring an OADM to change its drop channel. This unique design also includes architectural considerations of Disaggregated optical networks as per recent research. This design can be used by researchers, academicians in any SDON related research or training or network testing. The design is implemented and tested using OptiSystem simulator. The paper is organized into various logical sections, starting with "introduction" and "literature review". The next section 'problem domain' explains present challenges and defines the problem. The 'Solution methodology' section describes the proposed design explaining each step and design choices made. The next section "Results" shows the results of execution runs and confirms that the design works as desired. Then it leads to the final section 'conclusion'.**

***Index Terms*— SDN, Optical Transport Network, Disaggregated Optical Network, OpenFlow, GMPLS, ROADM, OptiSystem, SDON (Software Defined Optical Network)**

I. INTRODUCTION

Global mobile data traffic forecast by ITU, indicates data traffic growth of 50% year on year. In order to meet dynamic needs of today's cloud, mobility and content services, Telecom operators require more dynamic and programmable network infrastructure with high capacity. Existing networks are static and mostly manually provisioned. These are not capable of adapting to rapid changes to deliver the flexible services like cloud. Optical Transport Networks (OTN) promises the capacity and bandwidth demand, but can't offer programmability currently. Software Defined Networks (SDN) paradigm allows flexibility and programmability to network. But in present state, it is difficult to apply SDN to OTN, as it was originally conceived for packet-based IP networks.

Grenze ID: 01.GIJET.10.2.536

OTN has evolved differently from packet switched networks. To achieve protection (under 50ms) and restoration (under 100ms), it is necessary to have distributed control plane which is tightly coupled to the underlying NE. [1] Thus Network elements of OTN are vertically integrated (control plane and data plane reside in the same host), making it difficult to separately control them. This type of OTN architecture contradicts with basic premise of SDN i.e. to have Control plane separated from Data plane. This paper offers an innovative network design where control plane is separated physically from data plane.

In OTN, since it's a circuit switched network, the Path is selected at initial design time. Its more or less 'stitched' in the network. Changes to path requires tearing the existing path, then redesigning to select a new path, then manual step-by-step re-configuration of devices along the light path. Hence networks can't adapt to dynamically varying traffic conditions. For providing modern services via programmability in the network, it is essential to get a central network view. In this paper, a centralized control of Optical Ring network is demonstrated. Its uniqueness is in taking centralized decisions instead of at network each element level.

In OTN, its common to include all-optical network elements, such as optical switches, optical amplifiers, signal shapers, optical mux-demux. These do not require optical to electrical and back to optical (OEO) conversion. The ethernet network controller does not have capabilities to configure these all-optical network (NW) systems. At the time of writing this paper, no other known design offered ability to soft-programming OADM lambda, or dynamically configure Optical cross-connect (OXCs) for switching or bypassing a node. This paper uniquely presents a design that makes such dynamic configurations possible.

Key promise by SDN paradigm is that it brings "software defined" programmability in network control. SDN focuses on replacing the functions that traditionally run on a specialized hardware, with the software-realizations that run on commodity servers [6]. SDN usage software-based commands issued between control plane and data plane. This paper includes few steps carried out in software (e.g. in the form of running scripts for device configurations) that helps understand SDN-like software-based control.

The experimental design methodology was used to implement the design, run tests, collect the results and demonstrate outcomes. The type of experimental design chosen was simple comparative experiment. The input was given (WDM signal) and output was observed. Controlled variables include input signal wavelength, OADM's drop channel setting, OXC ports. The results were captured in the form of signal graphs shown on optical spectrum analyzer (OSA). This experiment was carried out using high-end Simulator called Opti System. Solution section explains why this was best fit.

II. Literature Studies

A detailed analysis of various articles was carried out. Cheng, Xu and others in their paper [2] explained the requirements for advanced network architecture of Packet Transport Network (PTN). It has good focus on fast provisioning, end-to-end network view. Although, it lacks consideration to OTN.

R. Vilalta et. al. in their paper [4] proposed a network control architecture for multidomain and multivendor network organized in layers. The abstract network layer and the control-specific layer, results in a mesh of generic SDN controllers on top of generalized multiprotocol label switching (GMPLS) protocols. The authors have clarified that application of this architecture are confined and has limited scope.

Verizon in its strategy publication [5] indicated their architecture for moving to 100G Packet-optical transport network. It deployed Fujitsu's FlashWave 9500 and the Coriant 7100 (formerly Tellabs 7100) P-OTS platforms. By terminating the aggregated SONET traffic at its edge central offices, it only has to deal with large Ethernet and OTN flows at the network node. It proposed vendor specific domain controller for each vendor's platform. The SDN controller will sit on top of it, making it a layered controller architecture.

Industry body Open Networking Forum (ONF) has also proposed [6] an architecture with a parent "super" controller. The network orchestrator will abstract the details of the optical transport layer. It provides open interfaces to client SDN applications and allows multi-technology controllers. This service is not easily realizable today due to vendor-specific NMSs, NEs from different vendors across path, end-user lacking configurability access through portal application.

Optical network model-based architectures claim to provide open and vendor agnostic management of optical equipment. Thomas Szyrkowiec et. al. have investigated [7] Optical Network Models and their application to SDN Management. They proposed an intent interface for creating virtual topologies which is integrated in the existing model ecosystem. This interesting architectural approach makes it easy to achieve software-based control but requires the network topology virtualization. In paper [10], a similar virtual modelling using VOLTHA was described, as an emerging standard for OLT (online termination) virtualization. The modelling approaches in [7] and [10] have limitations presently on a physical network level (related to assumptions for cross-connection, modelling physical network constraints etc).

A simplified architecture is proposed and analysed by RK Jha et. al. in their paper [8]. In this architecture, control of ethernet elements (routers) and optical ring is performed by a single SDN controller. Moreover, the architecture includes standardized hardware for OpenFlow switches and standard interface for OpenFlow communication. Communication between ethernet switches and optical network devices is setup using OEO converter. Communication between SDN controller and optical network devices is setup using OpenFlow agents. Hence this architecture will need enhancements before applying to all-optical network. Also, their ROADM combines the data plane along with switching control inside it, hence not fully SDN aligned.

Marist College along-with ADVA and IBM had setup an experimental testbed for carrying out research on Software Defined Optical Network. They have published Reference architecture paper [9] by C. DeCusatis, on the architecture they used in this experiment. This architecture achieves clear separation of data-plane and control plane. This setup allows path configuration using software portal app. But the architecture assumes specific HW nodes (such as FSP3000) for path configuration, hence its not generic and also not scalable. Additionally, the architecture does not consider disaggregated optical elements [10] which can limit its configurability and functionality.

III. MOTIVATION

OTN have specific characteristics different from packet-switched network. It underlines various specific considerations which are otherwise not applicable in packet-switched networks.[11] Hence it is difficult to apply SDN to OTN directly or to use the same SDN instance to manage both the domains, optical and ethernet. Changes are required on SDN side as well as OTN side to adapt so that SDON (Software Defined Optical Network) becomes a practical reality. A lot of research is ongoing in this area. Researchers need to carry out experiments involving multiple steps such as:

- study behaviour of all-optical transport network by applying SDN paradigm.
- They need to make changes on OTN side and/or SDN side and observe the network behaviour.
- They need to carry out tests and measurements of various aspects (BER, noise, setup delay etc).
- They need to quickly analyse their findings and redesign for additional runs

All these steps require a design that is:

- flexible and can be changed quickly,
- that is less cumbersome to analyse and measure,
- that is able to encompass key parameters of focus, without network vendor dependency
- and yet is realistic, feasible and is not totally different from actual deployments

This paper contributes by presenting a unique network design, which is easy to build and can be used for Research work, Network Testing setup, Integrations with other network in E2E scenario, Training and demonstrating on SDON. The readers can reuse this design as is (like a black-box) or use this design as a starting point and modify (white-box approach) as per their research needs.

A. Innovative Contents and contributions

The design proposed in this paper creates a way to achieve solutions that can be tested and reused in further research. The unique and innovative contents of the design include:

1) Programmability of all-Optical Network
2) Separation of control plane from data plan in all-optical network
3) Follows Dis-aggregation approach in data-plane, allows multi-vendor OADM, transponders.
4) Demonstrating the use case of dynamically changing OADM drop channel using OptiSystem

IV. PROBLEM DOMAIN

The SDN technology separates the control plane and data planes. This separation helps to introduce a new functionality by writing a software program that executes in control plane. This software program running within an external controller has a wider network view and can manipulate the logical map of the network. This provides the operator with the maximum flexibility for controlling different types of networks and dynamically match the service requirements. [12]. In OTN, while SDN attempts to reduce the light-path setup time, it adds complexity in control plane layer for all-optical networks [12]. Moreover, SDN based implementations expects clear separation of Control plane and Data plane from OTN.

To enable efficiency, traditionally, optical devices were vertically integrated [10] Also, the analogue nature of long distance DWDM optical communications causes technical complexity, needing vertical integration. While ONF (Optical Network Foundation) is working on ODTN research, researchers need an interim simpler design, to continue their research work, as the standard design project may take time.
Key aspect of SDN is ‘software defined’ network control to enable programmability. The design should facilitate a possibility of Software commands/configuration in control plane to control data-plane hardware.
The ability to obtain a central view of the complete network domain being managed, should reflect in the design. This means, the design should be able to demonstrate that it has visibility of all underlying components, connections and also the collective characteristics (like path) rendered.
SDN has standardized north-bound and southbound interfaces (SBI). OpenFlow is quite commonly used in packet networks for SBI mechanism (between control and data planes). The standard OpenFlow does not adapt to all-optical networks, it would require extensions to standard. At the time of writing this paper, existing standards used in SBI in all-optical networks (e.g. UNI, NNI) are insufficient to be used by SDN directly and are under research. Hence to avoid any bias towards OpenFlow, the design should consider a simple and neutral communication mechanism (as simple as query-and-response or send-and-receive).
A design that fulfils all these aspects will help researchers, in quickly and effectively build, analyse, demonstrate and test the behaviour of SDN managed all-Optical Transport network. Researchers can reuse this design in their SDON research work, academician can use it for training SDON concepts, in industry the design can help in testing network scenarios or for integration with another network setup.

A. Problem Definition

It’s a challenge to design an all-optical transport network incorporating concept of disaggregation and allow programmability by confirming to key SDN concepts viz:

a) control-plane and data plane separation
b) software defined instructions/commands to make data plane configurations
c) central view of NW domain available to control plane, (not at individual node level)

B. Statement

To come up with a network design for all Optical Transport Network, which has clear separation of Control plane from Data Plane and can be programmed like SDN by ability to take decision centrally.

C. Problem Formulation (Present Design in All-optical networks)

Present deployments of all-optical network domains are designed around Optical Ring formed by OADM (Optical Add-drop-multiplexers) which transports high bandwidth WDM signal (refer fig1.a) [13]. The optical cross-connects are co-hosted with OADMs (or inside them) and provide hardwired connectivity. Outside this domain, on the ingress and egress, are the non-optical components like IP routers, ethernet switches. Fig 1.b shows more detailed design of single OLT subsystem with OADM.

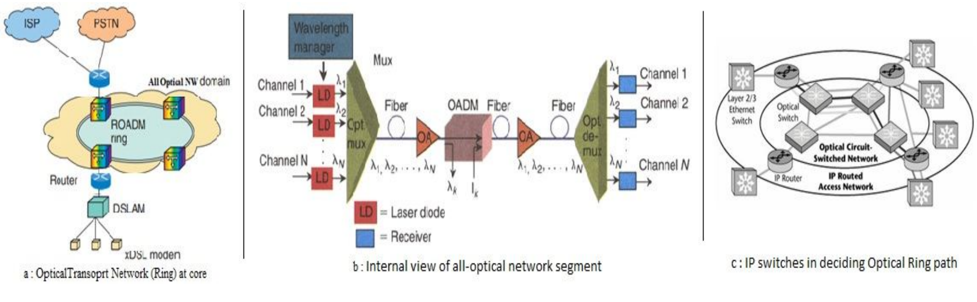

Figure 1: Present OTN setup and associated details

These traditional designs of optical network do not show control and data plane separation. As seen in Fig1.c the path or switching decisions are taken outside the optical domain (within the ethernet domain).

V. Solution Description

Coming up with an alternate design that can overcome the abovementioned limitation is a multi-step process. While a final tested design is mentioned in this paper, multiple designs were tried before this final solution.

A. Step1: Splitting the verticalized ROADM into optical line, OXC and optical ADM

It was quite obvious that the data plane design will have to use some type of OADM (Optical Add-drop-mux) only. OADM is very core to any OTN ring topology and will need to be preserved in design. Important consideration was given to optical cross-connects (or optical switches) placement and connectivity in the design. A lot of deliberation was done to achieve physical separation of OXC (optical cross connects) from data-plane OADMs. They needed to be logically connected with data-plane for control but not integrated or co-hosted within data-plane. This objective was achieved in the design as a first step.

B. Step 2: Detailed Design of all-optical Network, data plane, control plane, communication

Once step 1 was done, the focus of designing was shifted to detailing of Data-plane, control-plane and communication between them. The concept of OLT (Optical Line Termination) in disaggregated network [15] helped as guide-rails for Data-plane detailed design. The checklist and methodology for selection described in [10] by author was used to reconfirm this design choice. The design of data-plane consists of OADM, in-line amplifiers (ILA), tuneable filters, signal-shapers and optical links. As described in recent TIP whitepaper [16], a suggestion was taken to design a partially disaggregated optical network, without including transponders in the line system. This would help as transponders don't have to belong to the same vendor that makes OLT.

In control plane detailed design, care was taken to introduce the key differentiator (compared to traditional all-optical network) and involve software-defined control. Accordingly, the design achieved the control of OXC and optical switches in software, by using soft-configurations and/or scripts. The soft-configurations are stored in tabular form either in cache memory or in flat-file. This acts very similar to the flow-table entries in SDN OpenFlow tables. The scripts can be written to execute specific actions which is very similar to 'action-set' of flow-table entries. With these soft-configurations and scripts, the OXC and optical switches combined in central control plane makes the design similar to OpenFlow switches of SDN paradigm.

It can be noted that this control plane design has a central view of the underlaying all-optical domain and it control the decision about the path involved in data forwarding. As mentioned in above section (Problem Domain), neither the existing standard OpenFlow (without extension) nor the existing optical UNI/NNI protocols can be used as it is, for southbound communication to data-plane. Hence the author has chosen to keep the communication to minimal so that when the standards evolve, it can be plugged in for further betterment. Please refer to figure 2 for this detailed design.

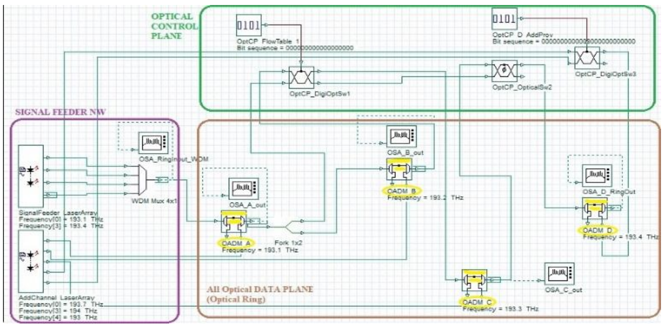

Figure 2: The design of OTN with data-plane & control-plane separation

C. Step 3: Selecting a simulator

Simulation are technology tools and they help with the unreal and real-life entities to be modelled on to the computer and run under certain predefined conditions [17][18] Network simulators are widely used by the research community to evaluate new theories and hypotheses. [19] Selection of simulator can impact the outcomes, hence sufficient analysis is required before selection, especially in optical network research. [20] The author has analysed many simulators and has come up with detailed approach to select simulator for research in OTN in his paper [21] (paper in press with IEEE). Using a simulator selection tool provided in [21] for ranking the simulators, OpiSystem simulator was ranked highest for implementing this design. It is specialized simulator for optical and includes all layers of OTN [22].

D. Step 4 : Building the designed network in simulator and ready the setup for running iterations

The next step is to use the simulator to build the design. Instead of vendor specific components, generic components were chosen from simulator library, to ensure that the design can be applied to any vendor hardware.

Some points can be skipped to make the design appears simple, e.g. connectivity links in simulator acts as a fiber so no need to add fiber-links explicitly. As multi-km fiber was skipped, in-line amplifiers were also skipped as focus is on NW view rather than signal characteristics. (Readers can add it if they want.)
After building the network in simulator, the Programming (scripting and by configuring simulator) part was undertaken in the realm of simulator. The OXC were configured such that programmatically they can toggle the path by selecting different out-ports (egress connection). The optical switch was programmed by a script (or configuration item) to switch as per the instruction and indicate action response. One OXC was also used to 'configure' the OADM's drop channel in data-plane. This scenario is the special feature of this design: the design is also able to program the disaggregated OADM component to dynamically drop configured channel.
The signal feeder network was also bit simplified, a WDM mux feeds 4 channels with wavelengths spacing of 100G. Each OADM is configured to drop one of these 4 wavelengths and add new lambda. Optical Spectrum Analysers (OSA) can be placed at various end-points to view and measure the output.

E. Step 5: Running the simulation demonstration

Now the setup is ready for execution and collecting outputs. Following 5 scenarios are demonstrated in this paper: (Please refer to figure 3 for pictorial illustration of these paths)

1. *Normal operation Path 1*: Ring-input is given to OADM-A, then goes to OADM-B, then to OADM-C, finally to OADM-D (as Ring output).
2. *Off-peak direct link Path 2*: Ring-input is given to A which directly flows into D and Ring output is observed. This use-case indicates off-peak temporary traffic burst of heavy data transfer.
3. *Path 3 with Node B bypass*: Ring-input is given to A, it skips B and goes to C, comes out from D
   This situation depicts path setup when OADM-B is down for maintenance or outage.
4. *Path 4 with Node C bypass*: Ring-input is given to OADM-A, then goes to OADM-B, skips OADM-C, comes out from OADM-D as Ring-output. This is situation depicts path setup when OADM-C is down for maintenance or outage.
5. Path 1-Corollary with dynamically changed Drop channel for OADM-D, changing the ring-out

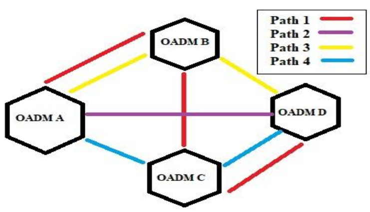

Figure 3: Illustration of different paths in the design

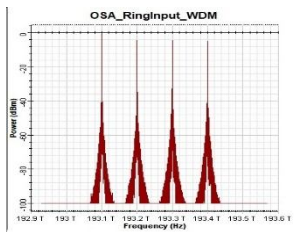

Figure 4: Ring Input

VI. RESULTS

This section presents results of all the 5 scenarios captured from OSA at various OADM output stages. The OADM Ring A-B-C-D is given the input WDM feed, that contains 4 channels 193.1THz, 193.2THz, 193.3THz and 193.4THz. This input is same for all the 5 scenarios, hence it is shown once, instead of repeating. (Please refer to fig. 4)

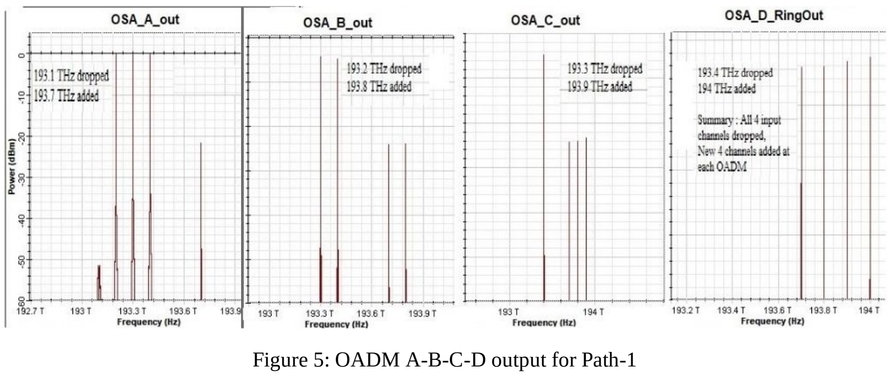

Figure 5: OADM A-B-C-D output for Path-1

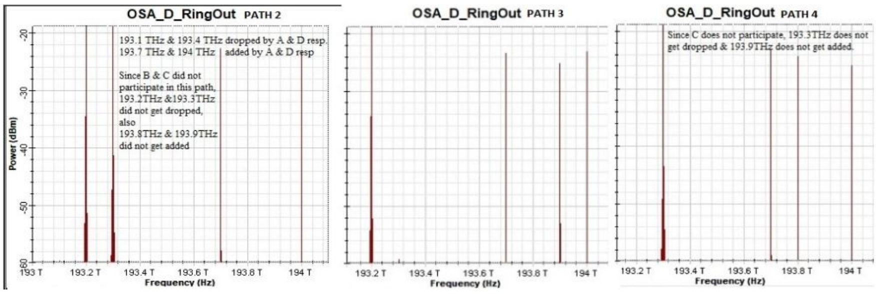

Figure 6: Ring output (at OADM-D) for Path-2, 3 and 4

A. Results of execution of Path 2, 3 and 4 : As shown in the Fig. 5 and Fig 6.

B. Data Model for all 5 scenarios

Optical Control Plane (OptCP) configurations used in all 5 runs, appears like openflow flow-table in fig.7.

	OptCP_FlowTable_1	OptCP_OpticalSw2	OptCP_D_AddProv	Path/ Action
Test Run	Bit sequence	Phase shift	Bit sequence	
1	000000000000000000	Pi	0000000000000000000000000	A - B - C - D
2	000000000000000000	Zero	0000000000000000000000000	A - D (off pk)
3	111111111111111111	Pi	0000000000000000000000000	A - C - D (skip B)
4	111111111111111111	Zero	0000000000000000000000000	A - B - D (skip C)
5	000000000000000000	Pi	1111111111111111111111111	A -B-C-D*(chg)

Figure 7: Optical Control Plane configurations in all 5 scenarios

C. Justification of the Results

As can be seen from results, the first 4 scenarios clearly demonstrated dynamic path programmability in all-optical ring network based on software commands in central control plane. The 5th scenarios shows device programmability whereby OADM add channel is dynamically programmed by central control plane (output similar to path-1, with different add channel). Though the standard Open Flow protocol could not be used, the SDN-like behaviour is observed. The results shows that the design works as desired.

VII. Conclusions

It is possible to apply SDN concepts to all optical transport networks. It is understood that SDN can not be applied to optical network in the same way it is applied to IP networks. There is a way to apply it to optical networks. It involves adapting SDN for optical networks (e.g. research on optical extensions). Additionally, it needs optical networks to be modified to adapt to SDN e.g. by clear separation of data-plane and control-plane, by implementing concepts of disaggregated OTN. This paper presents a design with optical control-plane and data-plane separated. Optical path is dynamically programmed in software, by a central control plane that has full view of optical ring network. This paper has successfully demonstrated SDN-like programmability in all-optical transport network. The design also show-cases a scenario of dynamically configuring a OADM drop wavelength. Researchers can reuse this design in their SDON research work. Academician can use it for training SDON concepts. In industry the design can help in testing network scenarios or for integration with other network setup. As a future work, this design can be further enhanced to strictly comply with SDN-OpenFlow or using OpenFlow extension for optical in SBI.

Acknowledgment

The author is thankful to OptiSystem for temporarily providing trial usage license for this academic research.

References

[1] Infonetics SDN and NFV Strategies: Global Service Provider Survey, March 2014, Document No.: PMC-2150738
[2] Weiqiang Cheng, ACTN Use-cases for Packet Transport Network, China Mobile, IETF, Jul 2014
[3] S. K. N. Rao, SDN and its Use-Cases - NV and NFV: A State-of-the-Art survey, presented at NTIL 2014 event

[4] R. Vilalta et. al, Control and Orchestration of Multidomain Optical Networks With GMPLS as Inter-SDN Controller Communication, Journal of Optical Communications and Networking Vol. 7, Issue 11, pp. B46-B54
[5] Verizon readies its metro for next-generation P-OTS, Gazettabyte, June 2014
[6] ONF-TR 538 : Use Cases for Carrier Grade SDN
[7] Thomas Szyrkowiec, Achim Autenrieth and Wolfgang Kellerer,Optical Network Models and Their Application to Software-Defined Network Management, International Journal of Optics, Volume 2017
[8] Rakesh Kumar Jha and Burhan Num Mina Llah, SDON: proposed architecture and comparative analysis, Journal of the European Optical Society-Rapid Publications (2019)
[9] Casimer DeCusatis, Reference Architecture for Multi-Layer Software Defined Optical Data Centre Networks, Special issue SDON in Electronics 2015, pp633-650
[10] Vishal Vasant Deshpande, Analysis of Innovations in OTN Interconnects, International Journal of Advanced Research in Computer and Communication Engineering, Vol. 10, Issue 7, pp32-40
[11] Vishal Vasant Deshpande, Analysis of Transformation of OTN into SDN Network Architecture, 2nd International Conference on Recent Innovations in Engineering & Technology 2020
[12] Mahmoud Bahnasy and others, Software-defined DWDM optical networks, Globcomm 2014 – Optical Networks and Systems Symposium
[13] Shinji Matsuoka, Ultrahigh-speed Ultrahigh-capacity Transport Network Technology for Cost-effective Core and Metro Networks, Featured Article, NTT Network Innovation Laboratories Yokosuka-shi
[14] Lillian G, KW Jarrett Telecommunications Essentials, Second Edition: The Complete Global Source
[15] ODTN introduction from official ODTN website https://opennetworking.org/odtn/
[16] Open Transport SDN Architecture Whitepaper, Copyright © 2020 Telecom Infra Project, Inc.
[17] J. Heidemann, K. Mills, S. Kumar, Expanding Confidence in Network Simulation, IEEE Net-work Magazine, Vol. 15, No. 5, Apr. 2000, pp. 58- 63.
[18] Siraj, Saba, A. Gupta, and Rinku Badgujar. Network simulation tools survey, International Journal of Advanced Research in Computer and Communication Engineering Vol. 1, Issue 4, pp. 199-206, 2012.
[19] Atta ur Rehman Khana, Sardar M. Bilalb, Mazliza Othmana, A Performance Comparison of Network Simulators for Wireless Networks, IEEE International Conference on Control System, Computing and Engineering, Malaysia, 2012, pp. 34-38
[20] Vedran Miletić, Branko Mikac, Matija Dzanko, Modelling optical network components: A network simulator-based approach, ResearchGate Conference Paper, October 2012
[21] Vishal Vasant Deshpande, Dr. S. P. Mohani, A comparative study of Network Simulators with focus on OTN (Optical Transport Networks), IEEE-explore 2023-24, paper is under-press to be published soon
[22] Optisystem product website https://optiwave.com/products/optisystem