Dual Use SDN Controller for Management and Experimentation in a Field Deployed Testbed

Jiakai Yu[1], Craig Gutterman[2], Artur Minakhmetov[3], Michael Sherman[4], Tingjun Chen[2], Shengxiang Zhu[1], Gil Zussman[2], Ivan Seskar[4] and Daniel Kilper[1]

[1]*College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA*
[2]*Electrical Engineering, Columbia University, New York, NY 10027, USA*
[3]*LTCI, Télécom Paris, Institut Polytechnique de Paris, 19 place Marguerite Perey, Palaiseau, FR 91120*
[4]*Electrical and Computer Engineering, Rutgers University, Piscataway, NJ 08854, USA*
jiakaiyu@email.arizona.edu; dkilper@optics.arizona.edu

Abstract: An SDN controller is developed for both testbed management and experimentation for the optical x-haul network in the COSMOS testbed providing a service-on-demand and reconfigurable platform for 5G wireless experiments coupled with edge cloud services.
OCIS codes: (060.4250) Networks; (060.2330) Fiber optics communications.

1. Introduction

The evolution of 5G and beyond mobile network is expected to address current network issues around capacity, latency, and flexibility. In order to cope with the exponential growth of wireless traffic demands from various services and applications, such as cloud computing, virtual reality, and video streaming, new radio access network (RAN) architectures require novel underlying optical networks to offer ultra-low latency, large capacity, and on-demand services [1 2]. Driven by the application requirements, investigation of these new technologies and architectures with the applications in field deployed situations becomes imperative. Technological integration of wireless, optical, and computing for delivering of high data rates and ultra-low latency has not been previously encountered. In addition, awareness of the underlying network performance constraints for applications development is requisite. The global effort to address these challenges in 5G and beyond networks has led to the development of multi-technology testbeds, often in field deployed environments centered around smart city and advanced wireless applications [3]. Open optical testbeds provide novel and customized infrastructure for experimentation on optical-wireless 5G architectures converged with software-defined networking (SDN), core/edge cloud, or user-end services and applications.

The Cloud Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment (COSMOS) platform is a programmable city-scale new RAN testbed being deployed in upper Manhattan, NYC [4 5]. The SDN based optical x-haul network provides various network functions on underlying infrastructure for both industrial and academic researchers with novel experiments and investigation on 5G networks merging reconfigurable optical networks, mobile radio technology, and cloud computing.

2. Optical Architecture and SDN Controller in COSMOS

The COSMOS optical x-haul network core in the Computing Research Facilities (CRF) at Columbia University is mainly composed by two types of optical equipment: Calient 320×320 S320 Space Switch (SS) and Lumentum twin 1×20 reconfigurable optical add/drop multiplexing (ROADM), shown in Fig. 1(a). The Calient SS provides high-dimension reconfigurable optical link connections for various optical and wireless devices connected to it. The Lumentum ROADMs connected to the S320 provide flexible and efficient optical wavelength resource allocation for higher layer services and applications by using wavelength division multiplexing (WDM). The ROADM/WDM networks can support fully-transparent and flex-grid optical links up to 96 channels for maximum capacity per link. With flexible configuration, high capacity, and low latency optical infrastructure, the COSMOS testbed can offer two important capabilities for research experiments on 5G wireless communication coupled with edge cloud computing: 1) high degree and reconfigurable network topology for large numbers of radio node and edge cloud connections. 2) multi-layer optical networking for experiments on various optical systems and architectures with novel optical equipment controlled by SDN/NFV. Fig. 1(a) also shows some long-term Calient S320 connections with various Ethernet/wireless devices and main facility locations, such as Top of Rack (ToR) switch for wireless radio node test, and the WiMNet Lab located in the Schapiro Center (CEPSR) of Columbia University. In order to emulate real distance between Edge Cloud and Central Cloud, users can reconfigure optical link connections to pass the optical signal through 32 Avenue of the Americas (32 AoA) for a loop of 22km.

All optical devices are controlled by a dedicated Ryu SDN controller [6]. Fig. 1(b) presents the optical SDN control scheme and functional modules. A local PostgreSQL database is designed to store all offline and online information from optical network. The offline data mainly consists of long-term physical information, such as device/location IP, device type, and fixed fiber links. The online data are abstracted from the Ryu SDN controller to assist controller functions such as topology reconfiguration, optical Label-Switched Path (OLSP) backup, and network recovery. The Ryu SDN controller initializes with network data from PostgreSQL offline data (normal startup) or online data (network recovery), and then saves all network information to its Traffic Engineering Database (TED) to avoid slow read processing from PostgreSQL during network control. The TED maintains all traffic, light-path, and physical layer information of all optical devices in the testbed. Network Monitoring, Domain Control & Management, and Path Computation modules collaborate with TED to handle all setup events on the optical physical layer. The Domain Control & Management is the core logical control module that deals with all northbound events from user/application via HTTP/JSON and all southbound events from the physical layer via various protocols depending on devices. The Path Computation module obtains network resource and runs Routing and Wavelength Assignment (RWA) for optical light-path and switching setup. For optical controllable components in COSMOS, the Calient S320 is controlled through OpenFlow/Telnet and the Lumentum ROADM is controlled through NETCONF/YANG. The physical functional control modules are presented in Fig. 1(c). With the Ryu SDN controller, Calient S320 SS and Lumentum ROADMs can be reconfigured to support various optical connection requirements from connected servers and research devices through the top-layer user/application.

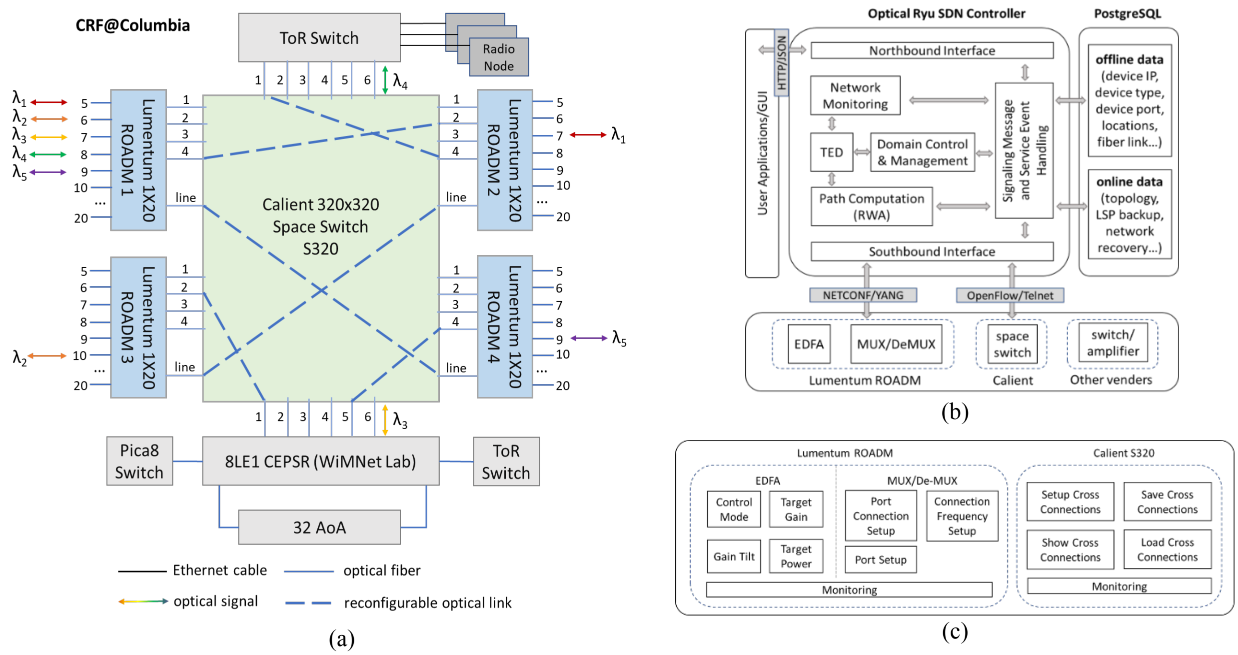

Fig. 1. (a) COSMOS Optical Network at Columbia University. (b) Ryu SDN controller design. (c) SDN controllable optical physical layer components.

3. Light-path Setup and Optical Space Switching with SDN Control in COSMOS

Fig. 2(a) shows the optical devices that we deployed in CRF at Columbia University. The SDN controller can handle two main types of operations on the COSMOS optical physical layer: 1) light-path connection setup, and 2) optical space switching setup. For light-path connection configuration, a user can request a service for new light-path connections or established light-path connections. Fig. 2(b) illustrates the light-path connections handled by the SDN controller. With request information provided by users, the SDN controller executes a series of procedures such as user identity/credential validation, TED information retrieve, RWA, and OLSP setup request. The Lumentum ROADM will receive the OLSP setup request with information including assigned ID, port connection, uni-direction/bi-direction, channel frequency, and bandwidth requirement and a successful setup will update the TED and PostgreSQL database and user/application.

Optical space switching is a featured function of the COSMOS optical platform that allows for novel topology reconfiguration and device insertion. The optical space switching procedure is illustrated in Fig. 2(c). When an optical space switching request is sent to the SDN controller, regular authentication and logical control is performed including the light-path connection setup request. The space switching operation can be directly applied on the Calient S320 if there is no protected OLSP light-path along the S320 link that will be disconnected by space switching. This type of space switching is called fast space switching that usually happens when a few S320 links are required to be reconfigured or network resources are lightly used. Once the space switching is effective, both TED and PostgreSQL will update traffic light-path information and physical link topology.

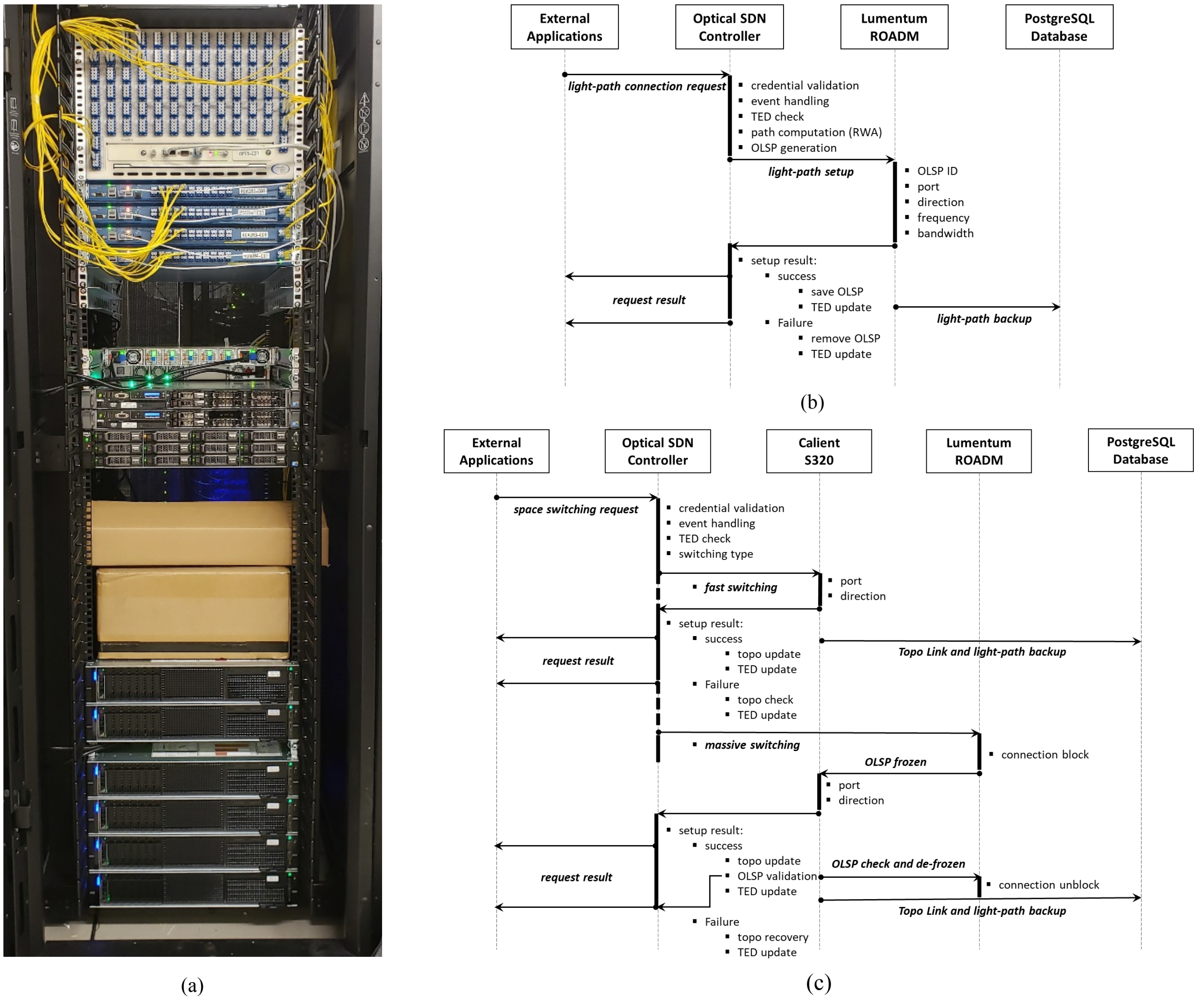

Fig. 2. (a) Optical infrastructure and edge cloud servers in COSMOS at Columbia University. Top white box is Calient S320 space switch, 4 blue boxes are Lumentum ROADMs, middle shelves are ToR switches, and bottom shelves are servers; (b) light-path connection setup signaling schema; (c) optical space switching setup signaling schema.

Another type of space switching is called ‘massive switching’. It requires a large number of S320 links to be reconfigured to form a new network topology. The difference between the two types of space switching is that massive switching will block all OLSP light-path that will be affected by space switching before the S320 link reconfigurations proceed. Once switching is done, all frozen OLSP light-paths are released and then examined for their working status. Rerouting will be applied to recover each OLSP connection when original routing path is not available. All unprotected OLSP will be removed when failed in the new network topology and the request will fail if any protected OLSP recovery fails. In this way a wide variety of topologies can be realized for experimentation. This work was supported by National Science Foundation (NSF) under grants CNS-1827923, CNS-1650669, CNS-1650685, CNS-1737453, ECCS-1547406, and IIP-1601784.

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