Programmable Optical x-Haul Network in the COSMOS Testbed

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

[1]Electrical Engineering, Columbia University, [2]LTCI, Télécom Paris, Institut Polytechnique de Paris, [3]College of Optical Sciences, University of Arizona, [4]Electrical and Computer Engineering, Rutgers University

***Abstract*—The Cloud-Enhanced Open Software Defined Mobile Wireless Testbed for City-Scale Deployment (COSMOS) platform is a programmable city-scale shared multi-user advanced wireless testbed that is being deployed in West Harlem of New York City [1]. To keep pace with the significantly increased wireless link bandwidth and to effectively integrate the emerging C-RANs, COSMOS is designed to incorporate a fast programmable core network for providing connections across different computing layers. A key feature of COSMOS is its dark fiber based optical x-haul network that enables both highly flexible, user defined network topologies and experimentation directly in the optical physical layer. The optical architecture of COSMOS was presented in [2]. In this paper, we show the tools and services designed to configure and monitor the performance of optical paths and topologies of the COSMOS testbed. In particular, we show the SDN framework that allows testbed users to implement experiments with application-driven control of optical and data networking functionalities.**

I. Introduction

High capacity SDR mmWave, full-duplex, and large/distributed MIMO access points in COSMOS will need substantial baseband computing resources in the RAN. This situation motivates the development of front and mid-haul (or x-haul) C-RAN capabilities for investigating different approaches to offloading a node's workload to an infrastructure-based, more powerful edge computing cluster. The COSMOS optical network design makes use of wavelength division multiplexing (WDM) and optical switching to provide two important capabilities: (i) flexible experimentation and network topology reconfiguration of large numbers of radio and computing connections, and (ii) multi-layer optical networking for experimentation on novel optical devices, systems, SDN/NFV optical control planes, and optical architectures. Fig. 1 shows the design and architecture of COSMOS' core optical network connecting the large radio nodes shown in the bottom inset.

The SDN framework will allow testbed users to experiment with application-driven control of optical and data networking functionalities, and radio resources. Moreover, it will support visualization and will allow for logical separation of the same radio or network resource into multiple distinct networks with their own topology and routing protocol. The open network operating system (ONOS) platform and Ryu OpenFlow controller will be used as standard platforms for SDN and NFV experimentation. In this demo, we will showcase the tools and services designed to configure and monitor the performance of optical paths in the COSMOS testbed.

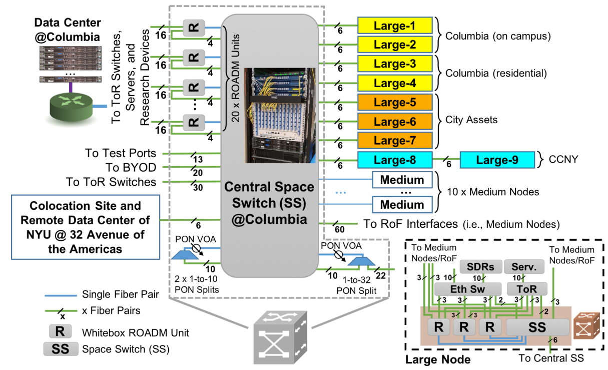


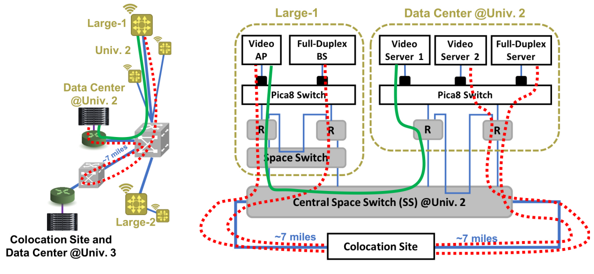
Fig. 1. COSMOS' core optical switching architecture and the switching architecture of a large node.

II. Example Experiments

Fig. 2(a) demonstrates the motivation for the programmable optical architecture by showing a case in which COSMOS' core optical switching architecture, which allows for creating experiment- and application-driven networking topologies to emulate a variety of distances for C-RAN remote computing. For example, a large node (Large–1 at Columbia University) can perform computing at the data center at Columbia University through a short optical route (green, with $<$1 mile distance), or through a long optical route using dark fiber to the colocation site provided by the city (red, with $\sim$14 miles round-trip distance).

An optical-wireless x-haul experiment has been developed to demonstrate the C-RAN architecture and its integration with the optical x-haul network and SDN control. The experimental setup is shown in Fig. 2(b). In particular, the wideband full-duplex radio, described above [3], serves as an full-duplex base station located at Large–1. The base station sends baseband IQ data over the dark fiber to the optical switches at the remote data center of NYU at 32 Avenue of Americas (AoA). It is then sent back to the data center at Columbia University for digital signal processing using NI LabVIEW (red route with $\sim$14 miles distance).

Simultaneously, a video multicast application [4] operates on the x-haul network on a different optical wavelength. The AP, which needs to dynamically adapt to the channel conditions of several users, receives video streams from two



(a) (b)

Fig. 2. (a) Example of optical x-haul network topologies that can be created by COSMOS's optical transport network with SDN control, and (b) The optical paths in an example optical-wireless x-haul experiment.

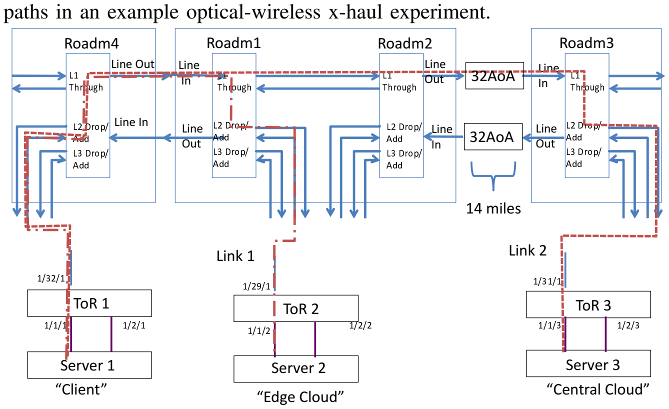


Fig. 3. COSMOS' optical experiment: optical light path switches between the Edge Cloud and Central Cloud.

servers through *on-demand optical switching* managed by a Ryu-based SDN controller [5]. One is received through the short green route (<1 mile distance), and the other through the long red route (∼14 miles distance). The experiment evaluates the ability of the multicast application to switch between a local and remote cloud servers (via optical support) while responding to the users' channel states.

Additional future research enabled by the programable optical layer include Edge Cloud, Augmented Reality, Virtual Reality, and Smart City Intersections.

III. Demonstrations

The demo will show the tools and services designed to configure and monitor the performance of optical paths on the COSMOS testbed. The SDN framework will allow testbed users to implement experiments with application driven control of optical and data networking functionalities. All of the details are provided on the wiki page of COSMOS project [6].

COSMOS testbed provides a possibility to create and use optical networks of various topologies. An example of how an optical network could be configured and used is provided. A simple experiment on switching of optical paths is presented in Fig. 3. The experiment consists of switching the light path from a C-RAN in the "Edge Cloud" to the "Central Cloud". The extended path to the "Central Cloud" is emulated by using the optical fiber connection to 32 Avenue of Americas. The initial optical connection is established from the top of rack switch (ToR) 1 to ToR 2. The optical path is then switched to a new path from ToR 1 to ToR 3.

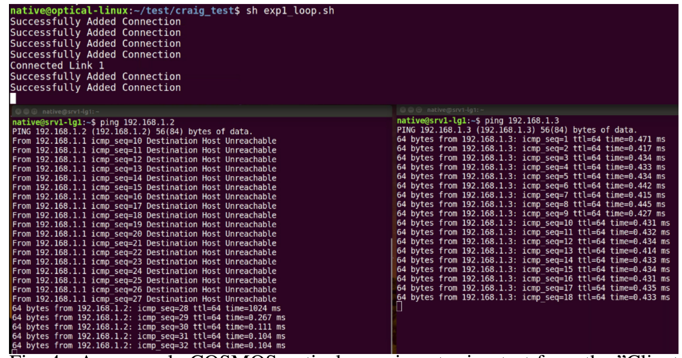


Fig. 4. An example COSMOS optical experiment: ping test from the "Client S320 Space Switch" to the "Edge Cloud" and the "Central Cloud".

The demo setup includes 3 COSMOS servers that are interconnected through 4 ROADM units. The 4 ROADM units are set up to create two 1-degree ROADM node, and one 2-degree ROADM node. The ROADM units need to be connected correctly to each other and to the ToRs. The programmable ROADM units allow for setting up the topology based on experimental requirements. All the created fiber links are with bandwidth of 10 Gbps and are set to 1553.30] nm ([192.95; 193.05] THz). The ROADM units are configured using customized Python scripts and/or the Ryu controller.

All interconnections go through the central Calient S320 space switch as shown in Fig. 1. The interconnections on the Calient S320 need to be configured properly to enable wavelength passage on the ROADM units. This configuration is also done using the Python scripts or the Ryu controller.

The first path is established by connecting the "Client S320 Space Switch" to the "Edge Cloud". When the user wishes to switch to the "Central Cloud", a second script is run and the underlying optical path is switched. After configuration of all the interconnections for "Client" and "Edge Cloud", a ping message is sent from the "Client" to each server (Fig. 4). The latency from the client to the "Edge Server" is measured to be around 0.1 ms. When the switches are re-configured to connect to the "Client" to the "Central Cloud", the measured latency is increased to around 0.4 ms due to the longer dark fiber path (14 miles distance compared to less than 1 mile distance).

In addition to the default demo set-up, we request direct Internet Acess. This would allow us to demonstrate to users in real time how to use the optical reconfiguraiton software.

References

[1] "COSMOS," https://cosmos-lab.org/, 2019.

[2] J. Yu, T. Chen, C. Gutterman, S. Zhu, G. Zussman, I. Seskar, and D. Kilper, "COSMOS: Optical architecture and prototyping," in *Proc. OSA OFC'19*, 2019.

[3] T. Chen, M. B. Dastjerdi, J. Zhou, H. Krishnaswamy, and G. Zussman, "Wideband full-duplex wireless via frequency-domain equalization: Design and experimentation," in *Proc. ACM MobiCom'19 (to appear)*, 2019.

[4] V. Gupta, C. Gutterman, Y. Bejerano, and G. Zussman, "Experimental evaluation of large scale WiFi multicast rate control," *IEEE Trans. Wireless Commun.*, vol. 17, no. 4, pp. 2319–2332, 2018.

[5] Y. Li, W. Mo, S. Zhu, Y. Shen, J. Yu, P. Samadi, K. Bergman, and D. C. Kilper, "tSDX: Enabling impairment-aware all-optical inter-domain exchange," *J. Lightwave Technol.*, vol. 36, no. 1, pp. 142–154, 2018.

[6] "Setting an Optical Network on COSMOS Testbed," https://wiki.cosmos-lab.org/wiki/tutorials/optical-network-example, 2019.