Programmable Optical x-Haul Network in the COSMOS Testbed

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***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 abstract, we present the tools and services designed to configure and monitor the performance of optical paths and topologies of the COSMOS testbed. In particular, we present the SDN framework that allows testbed users to implement experiments with application-driven control of optical and data networking functionalities.**

I. Introduction

High capacity millimeter-wave, full-duplex, and large/distributed MIMO technologies deployed in the city-scale programmable COSMOS test need substantial baseband computing resources in the radio access network (RAN). This situation motivates the development of front-, mid-, and back-haul (or x-haul) cloud-RAN (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 with novel optical devices, systems, software-defined networking (SDN) optical control planes, and optical architectures. Fig. 1 shows the design and architecture of COSMOS' core optical network, where the optical switching for a large COSMOS radio node is shown in the bottom inset.

COSMOS' SDN framework allows testbed users to experiment with application-driven control of optical and data networking functionalities, as well as radio resources. Moreover, it supports visualization and allows for logical separation of the same radio or network resource into multiple distinct networks with their own topology and routing protocol. The

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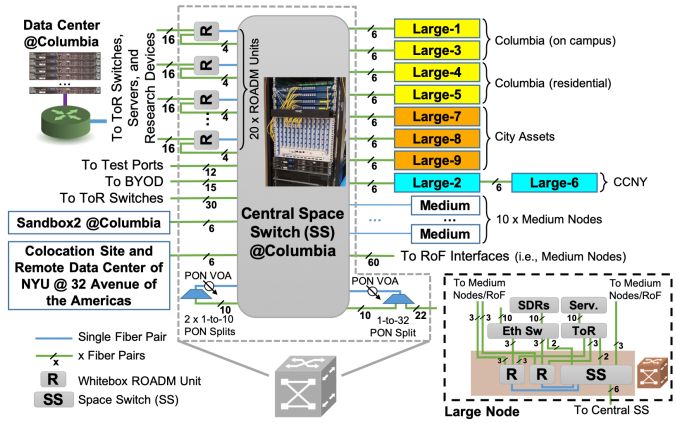


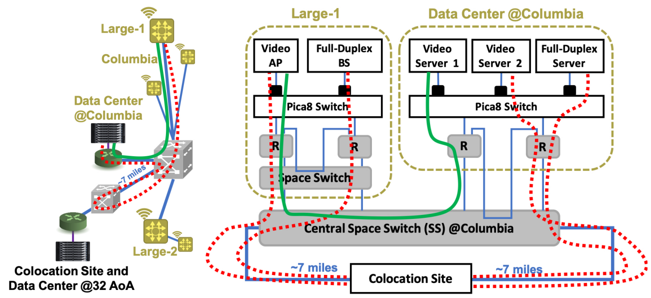
Fig. 1. COSMOS' core optical switching architecture and the switching architecture of a large node.

open-source open network operating system (ONOS) platform and Ryu OpenFlow controller will be used as standard platforms for SDN and network functions virtualization (NFV) experimentation. In this demo, we showcase the tools and services designed to configure and monitor the performance of optical paths in the COSMOS testbed.

II. Example Experiments

The COSMOS testbed provides users the capability to configure and experiment with optical networks of various topologies. The tools and services designed can be used to configure and monitor the performance of optical paths in the COSMOS testbed. This implemented SDN control framework allows testbed users to implement experiments with application-driven control of optical and data networking functionalities. All of the details are provided on COSMOS project website [3]. Future research enabled by a programmable optical layer include edge cloud, augmented reality, virtual reality, and smart city intersections.

Fig. 2(a) demonstrates the motivation for COSMOS' programmable core optical switching architecture, where experiment- and application-driven networking topologies can be configured 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, facilitated by NYC, to the colocation site at



(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.

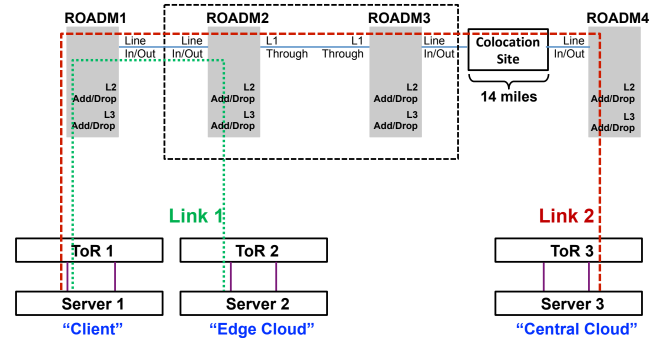


Fig. 3. COSMOS' optical experiment: optical light path switches between the Edge Cloud and Central Cloud.

32 Avenue of the Americas (AoA) (red, with ∼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 in [4], 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 colocation site and remote data center of NYU at 32 AoA. It is then sent back to the data center at Columbia University for digital signal processing using the NI LabVIEW software.

Simultaneously, a video multicast application [5], [6] operates on the x-haul network on a different optical wavelength. The access point (AP), which needs to dynamically adapt to the channel conditions of several users, receives video streams from two servers through *on-demand optical switching* managed by an open-source Ryu-based SDN controller [7]. One is received through the short green route, and the other through the long red route. 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.

III. Programmable Optical Capabilities in the COSMOS Testbed

We now present an example experiment to demonstrate the capability to switch optical paths in the COSMOS testbed. Fig. 3 shows the experimental setup, where 3 COSMOS servers are interconnected through 4 reconfigurable optical add-drop multiplexer (ROADM) units. A laptop is used to remotely login into the COSMOS testbed to execute the example experiment.

The programmable ROADM units allow for setting up the topology based on experimental requirements. The 4 ROADM units are set up to create two 1-degree ROADM nodes, and one 2-degree ROADM node. The ROADM units can be configured to connect to each other and to the top of rack switches (ToRs). All the created fiber links can be configured with the required bandwidth and optical wavelength. The ROADM units are configured using customized Python scripts and/or the Ryu OpenFlow controller. All interconnections go through the central Calient S320 320×320 space switch as shown in Fig. 1. The interconnections on the Calient S320 are configurable to enable wavelength passage between devices. This configuration is also done using customized Python scripts and/or the Ryu OpenFlow controller.

In this demonstration, we showcase the capability of switching the optical path in a C-RAN between the "Edge Cloud" to the "Central Cloud". The first path is established by connecting the "Client" 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. In particular, the extended path to the "Central Cloud" is emulated by using the dark fiber connection to the colocation site at 32 AoA. The initial optical connection is established from ToR 1 to ToR 2 and the optical path is then switched to a new path from ToR 1 to ToR 3. Performance metrics such as the round trip time and switching delay are also presented.

Acknowledgments

This work was supported in part by NSF grants CNS-1650669, CNS-1650685, CNS-1737453, CNS-1827923, ECC-0812072, and CNS-1650669. We thank NYC Mayor's office of the CTO and ZenFi for facilitating access to the dark fiber.

References

[1] "Cloud enhanced Open Software defined MObile wireless testbed for City-scale deployment (COSMOS)," https://cosmos-lab.org/.

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

[4] 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*, 2019.

[5] V. Gupta, Y. Bejerano, C. Gutterman, J. Ferragut, K. Guo, T. Nandagopal, and G. Zussman, "Light-weight feedback mechanism for wifi multicast to very large groups—experimental evaluation," *IEEE/ACM Trans. Netw.*, vol. 24, no. 6, pp. 3826–3840, 2016.

[6] 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.

[7] 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.