SDN-controlled Dynamic Front-haul Provisioning, Emulated on Hardware and Virtual COSMOS Optical x-Haul Testbeds

Bob Lantz[1], Jiakai Yu[1], Ayush Bhardwaj[2], Alan A. Díaz-Montiel[2], Aamir Quraishy[1], Steven Santaniello[1], Tingjun Chen[3], Rina Fujieda[1], Atri Mukhopadhyay[2], Gil Zussman[4], Marco Ruffini[2], and Dan Kilper[2,1]

[1]*College of Optical Sciences, University of Arizona, Tucson, AZ*
[2]*CONNECT Centre, Trinity College Dublin, Ireland*
[3]*Duke University, Durham, NC; [4]Columbia University, New York, NY*

[1]*rlantz@cs.stanford.edu, {jiakaiyu, aamirq, ssantaniello, rfujieda}@email.arizona.edu*
[2]*{aybhardw, adiazmon, amukhopa, marco.ruffini, dan.kilper}@tcd.ie*
[3]*tingjun.chen@duke.edu, [4]gil.zussman@columbia.edu*

Abstract: We demonstrate SDN-controlled dynamic front-haul optical network provisioning and modulation format adaptation, running on an emulation of the COSMOS testbed benchmarked against the COSMOS hardware testbed. © 2021 The Author(s)

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1. Overview

COSMOS [1] is a "city-scale programmable testbed for experimentation with advanced wireless." This testbed, currently being developed and deployed in upper Manhattan, includes software-defined radio (SDR), edge, and cloud compute nodes, connected via a flexible, disaggregated, optical x-haul (front/back/cross-haul) network. The optical x-haul testbed [2] for COSMOS consists of network elements such as ROADMs, optical terminals and transceivers, fiber spools, and EDFAs, connected to a programmable optical circuit switch/patch panel, with software-defined networking (SDN) control for the ROADMs, circuit switch, and transceivers. In addition to enabling live experiments in the New York urban environment, the testbed can provide hardware emulation of extended network scenarios involving more complex networks than available in the street level deployment alone.

Although the COSMOS testbed has limited availability, and can typically only be used for one experiment at a time, we would like to enable multiple, concurrent groups of researchers and students to develop, test, and debug COSMOS experiments and SDN control applications, even when they do not have access to the hardware testbed, and to test larger network configurations with more devices than are available in hardware.

To this end, we have developed a prototype virtual COSMOS optical x-haul testbed, implemented in software on top of Mininet-Optical [3], an emulator for disaggregated, software-defined, packet-optical networks. In our demonstration, attendees will be able to observe a hardware SDN controlled wavelength switching experiment running on the COSMOS hardware testbed (fig. 2) and compare it with an interactive experiment running on Mininet-Optical set up to emulate the optical networking experiment in COSMOS (fig. 3). Notably, the Mininet-Optical based emulation is also used to expand the current capabilities of COSMOS, adding nodes, transceivers, and radio networking details either planned for COSMOS upgrades or that will not be available in COSMOS.

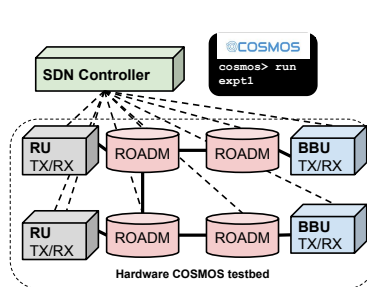Fig. 1: Experimental scenario – Metro front-haul provisioning.

Fig. 2: SDN controlled experiment on COSMOS optical x-haul testbed.
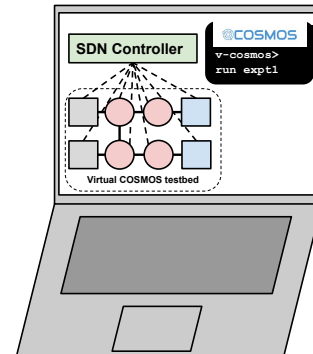
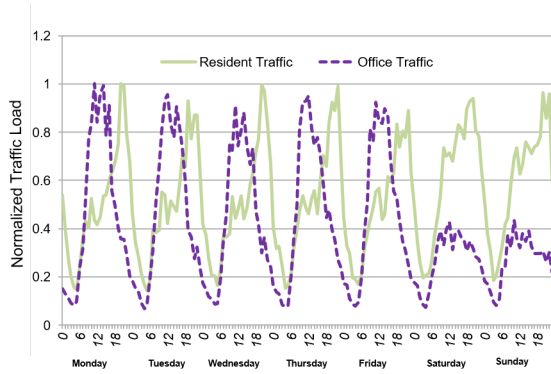Fig. 3: SDN controlled experiment running on virtual COSMOS testbed.

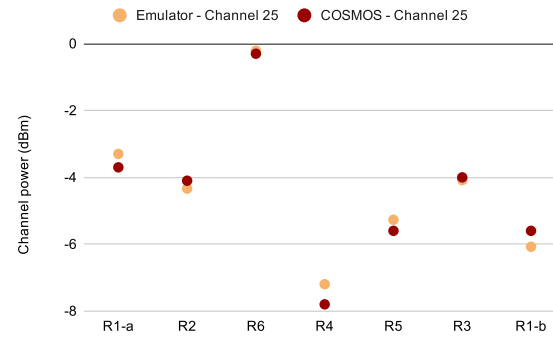Fig. 4: Diurnal residential/office traffic patterns.

Fig. 5: Channel power for emulated vs. hardware COSMOS testbed, for a ring of 6 ROADMs.

1.1. Experimental Scenario

Our experimental scenario (fig. 1) models a metro x-haul network that routes front-haul RF signals encoded as symmetric 24.3 Gb/s CPRI streams between remote radio units (RU) and baseband units (BBU/DU/CU) at data center locations. This scenario uses a portion of the deployed network in COSMOS, which is extended using transmission in fiber spools to provide a hardware emulation of the route shown in the figure, based on Crown Castle (crowncastle.com/infrastructure-solutions) fiber routes. Our traffic pattern is based on a model [4] of residential and office traffic that changes according to the (modeled) time of day (fig. 4). In response to the varying traffic patterns, the SDN controller dynamically provisions lightpaths over a period of hours, to adjust the available capacity for RF signals and routing them to the BBUs across ROADM switched optical links.

1.2. Design and Implementation

This scenario is implemented in both an emulated version of the optical x-haul network in COSMOS (fig. 3) and using hardware to emulate the larger metro network within the physical COSMOS testbed (fig. 2). Both testbeds will be configured as a metro access distribution arc or horseshoe network that connects two data center locations with multiple RU aggregation points along the horseshoe, and handles the varying traffic demands of fig. 4 over (virtual) time, scaled based on the population densities at the locations. Network elements in COSMOS are emulated using Mininet-Optical software components such as `ROADM`, `OpticalLink/Span/Amplifier` and `Terminal`, configured using an `OpticalTopo` topology template. The current deployment in COSMOS only supports six whitebox ROADM units and therefore only four of the nodes in the six node network. However, Mininet-Optical enables experimentation with the full six node network.

Our SDN controller monitors and responds to dynamic network conditions; for example, if the BER or estimated received gOSNR at the transceiver for a particular lightpath falls below a threshold, the SDN controller raises an alarm and reduces the modulation format constellation down from 16QAM (200 Gb/s) to QPSK (100 Gb/s) or even BPSK (50 Gb/s), rerouting signals and re-provisioning lightpaths as necessary. The same SDN controller is used to control the emulated COSMOS network and the hardware COSMOS network. We will compare results across emulated and hardware testbeds, as in fig. 5.

The SDN controller configures the optical layer to meet metro wireless traffic requirements. Each aggregated radio signal uses 24.3Gb/s of optical capacity, which is multiplexed into a line side DWDM coherent transceiver and introduced at the add port of a ROADM. This capability will be available in future deployments of COSMOS, but uses emulated signals in the current deployment.

1.3. Preliminary Results

We demonstrate emulation of disaggregated optical network performance and behavior under SDN control. Fig. 5 shows channel power measured in our calibration runs using different sets of channels at varying power levels transmitted through whitebox ROADMs organized into a continuous ring of the 6 units deployed in COSMOS, compared with emulated results from Mininet-Optical. In the emulated experiment, the wavelength-dependent gain (WDG) function for the emulated EDFAs has been calibrated to match the WDG for the EDFAs in the hardware topology, measured beforehand under a full channel load. This figure shows the typical agreement in channel power levels, within 1 dB of hardware measurements.

We also demonstrate novel system behavior as our SDN controller reacts to dynamic traffic requests and evolving network conditions. For traffic demand arrivals, the controller will either multiplex the signal into a provisioned lightpath with available capacity along the selected route, or dynamically set up a new lightpath to provide the needed capacity. As the client RU traffic decreases, RU signals are removed and any idle lightpaths without data
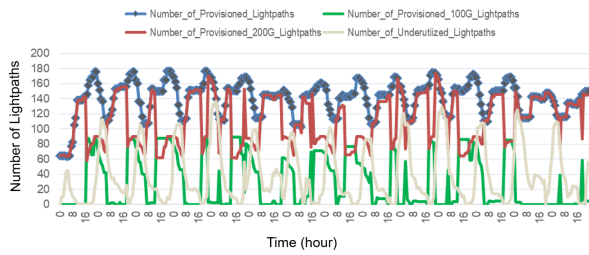
Fig. 6: Lightpath provisioning for a 4 node network with BBU processing limits.
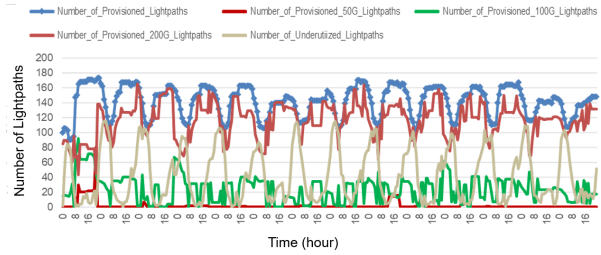

Fig. 7: Lightpath provisioning for a 6 node network with BBU processing limits.

traffic are torn down. Optical link capacity and modulation formats are dynamically reconfigured based on the received gOSNR values of each link. Building networks with selected nodes (fig. 1), fig. 6 shows how the SDN controller dynamically provisions and configures lightpaths on a 4-node network emulated on the software testbed for two weeks, analogous to what the hardware testbed supports, and fig. 7 shows provisioning for the full 6-node network (an underutilized lightpath has at least 50% available bandwidth to transmit RU traffic).

2. Innovation

We will present:

- SDN-controlled dynamic provisioning, monitoring, and rerouting for an experimental, disaggregated metro network segment, emulated on hardware and software testbeds
- The first public demonstration of our prototype software emulation of the COSMOS optical x-haul network testbed
- The first public demonstration and comparison of the same SDN controller and experimental configuration running on the software Virtual COSMOS testbed and the hardware COSMOS optical x-haul testbed
- An experimental SDN controller, developed primarily on the emulated Virtual COSMOS optical x-haul network testbed, running on the hardware COSMOS optical x-Haul network testbed
- The first validation of the Mininet-Optical [3] emulator's behavior and accuracy when running the same SDN controller and experimental configuration as a specific hardware testbed

3. OFC Relevance

This proposal responds directly for the call to demonstrations of SDN and associated software tools. In particular, we will demonstrate a live optical SDN experiment running interactively on our prototype virtual COSMOS optical x-haul network testbed and the actual hardware COSMOS optical x-Haul network testbed. Attendees will be able to observe and interact with the experiment and to compare its behavior on the emulated testbed with experimental results from the hardware COSMOS testbed.

We hope this demonstration will provide attendees with a hands-on experience of interactive SDN control of disaggregated, software-defined optical x-haul networks operating in a metro environment, as well as the use of an emulated testbed to enable offline experimentation and SDN controller development. Users will be able to modify the BBU processing limits and observe the impact on the lightpath provisioning.

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