# Demonstration of Low-Latency Coherent Optical Connectivity for Consolidated Inter-Hub Ring Architecture

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**Abstract:** Based on new design of consolidated inter-hub CDC architecture, end-to-end video delivery is demonstrated with 2-μs latency from multicast switch and 11μs from interoperable coherent muxponder, and full-duplex operation is also presented in such network. © 2020 The Author(s)

## 1. Introduction

Today, cable industry is rolling out plans for *10G Initiative* that provides 10G symmetrical speeds, lower latencies, enhanced reliability, and better security to the end users in a scalable manner [1]. A suite of key advances in cable and optical technologies will enable such 10G platform, including deeper fiber penetration, flexible and modular intelligent fiber nodes, spectrum expansion and DOCSIS® 4.0 technologies, all-IP services, and multi-layer network function virtualization. The evolution towards distributed access architectures (DAA) and the unique features of a cable-specific fiber access environment with only a few fibers available for a 500-household-passed serving area prompted the use of coherent optics to backhaul capacity from a large number of remote PHY devices (RPD) or remote MAC-PHY devices (RMD), small cells, and businesses within an original fiber node. Meanwhile, consolidation of hubs continues to the focus for cable operators in order to improve the capital expenditures (CAPEX) and operating expenditures (OPEX) in the process of the legacy infrastructure upgrade. As these demand for higher bandwidth and greater flexibility overwhelm the edge of the optical network, cable operators are evaluating reconfigurable optical add/drop multiplexers (ROADMs) to be utilized closer to the edge to enable efficient wavelength manipulation that are well suited for ring topologies. It is known that ROADMs have become an essential feature in backbone and metro networks for offering colorless, directionless, and contentionless (CDC) functions [2] to improve flexibility, survivability, and operational simplicity to current network. However, these benefits come with increased node cost and complexity, which restricts the application in optical edge and distribution network. Additionally, according to a recent operators' survey, 20 percent of existing cable access networks use a single-fiber topology. This means that downstream and upstream transmission to nodes takes place on a single strand of fiber. This number is expected to grow further in the near future. Therefore, in the consolidated inter-hub ring architecture, bidirectional transmission is needed for coherent signals to support single-fiber topologies.

This work provides a new design of a consolidated inter-hub optical ring architecture. It includes a simplified combination of wavelength selective switch (WSS) and multicast switch (MCS) to enable the operator greater flexibility to manage and optimize optical-layer resources through CDC capabilities. The muxponder-based high-definition video delivery is demonstrated for the first time over an interoperable 100G PM-QPSK coherent link within this inter-hub architecture. The contribution to end-to-end latency from different segment of the network has been measured. Moreover, full duplex coherent optics is also demonstrated for simultaneous bi-directional transmission over single fiber and single wavelength in this network.

## 2. Design of Consolidated Inter-Hub CDC Architecture

Figure 1 shows a schematic of new hybrid fiber-coaxial (HFC) architecture designed to deliver high-speed data and video to support a variety of services. The headend typically serves as the primary signal/content sources from satellite and microwave antennas and due to its central location may also serve as the interconnection points with other service providers. The headend (inset (I)) is connected to a few hubs (primary or secondary hubs) with an optical fiber ring network. In this new design, the wavelength manipulation is introduced through an architecture of route (via two 1x2 WSSs) in express path and select (via 4x4 MCS) with respect to local add/drop paths in the edge/distribution network for 2-degree headend on each ring. Because of the edge environment with limited insertion loss from transmission link and add/drop modules and the high signal sensitivity of coherent systems, the drop and even inline optical amplifiers (dashed amplification box) can be eliminated. The structure of a 4×4 MCS in the drop and add direction is also shown in Fig.1 as the inset (II). The top layer in an MCS is an array of 1x4 splitters, and the bottom layer is an array of 1x4 switches. The complex crisscrosses between the top-layer splitters and bottom-layer switches are in a planar lightwave circuit (PLC) based on a silica-on-silicon chip. This configuration can offer CDC functions and a lower cost and complexity comparing to current deployed metro/backbone ROADM solutions. With respect to the hubs that are connected to fiber nodes using coherent optical link, such as hub B (inset (III)), network consolidation can be performed to shift some functions to adjacent optical hubs and only leave optical layer with 2-degree WSS and 2x4 MCS. It is noted that the number of add/drop channels can be expandable from 4 to 8, 16, etc. [3-4]. In this designed architecture, each fiber node terminates the point-to-point coherent optical link that originated at the headend or hub, and outputs multiple optical or electrical Ethernet interfaces operating at lower data rates (typically 10G) to connect devices that are either co-located with the aggregation node and/or exist deeper in the network. This aggregation or disaggregation function can be done by a router, an Ethernet switch, or a muxponder, depending on the DOCSIS/PON/business traffic demand, cost, scalability/flexibility/reliability, and other operational considerations. The distance between the hub and aggregation node typically less than 40 km, and the distance from the aggregation node to each end point is less than 3 km. This work focuses on muxponder-based coherent solution.

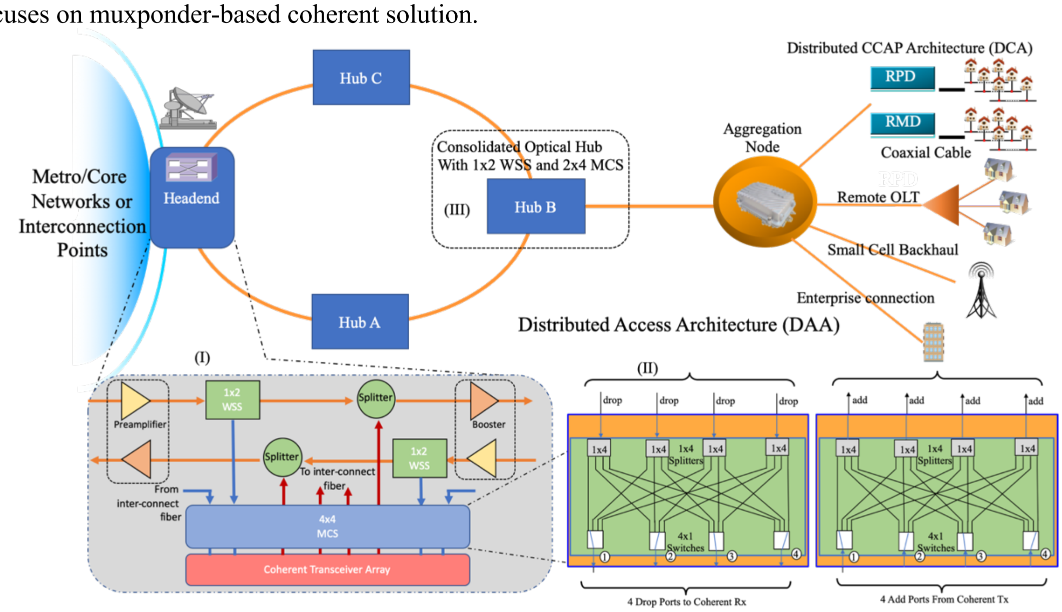


Fig. 1. Architecture design of inter-hub network with CDC functions.

## 3. Latency Measurement

Fig. 2 (a) presents an overall view of the experimental testbed for video streaming over muxponder-based coherent link in inter-hub ring architecture. Video streaming traffic is generated in a laptop and transmitted to a 10GigE switch. One of the SFP+ is then connected to the muxponder (from ADVA OD6) through the Multi-fiber Push On (MPO) connector. This muxponder can aggregate 10x10G services mix into a single 100G wavelength trunk or 20x10G services for a single 200G channel. A C-form factor pluggable 2 – digital coherent optics (CFP2-DCO) is employed as the line-side interface and configured to support dual polarization differential QPSK (DP-DQPSK), a symbol rate of 27.95 Gbaud with the Staircase HD FEC complying with the CableLabs' P2P Coherent Optics Physical Layer 1.0 (P2PCO-SP-PHYv1.0) specification for coherent interoperability test [5]. The coherent signal

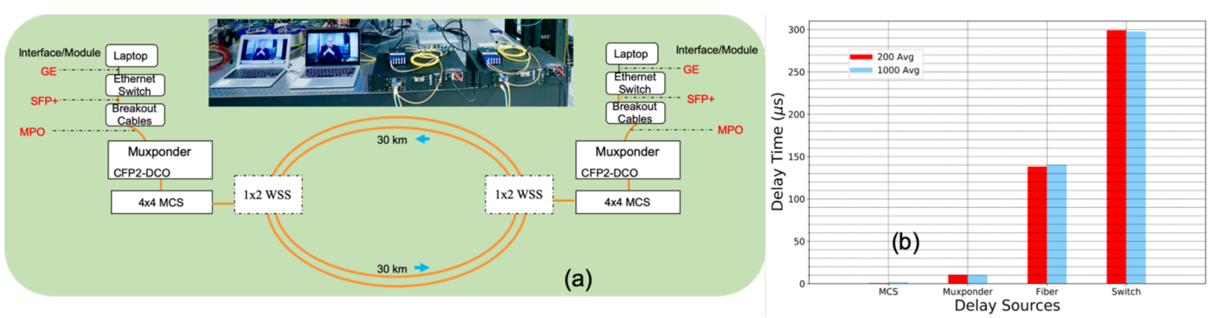


Fig. 2. Muxponder-based video delivery (a) and latency measurement results (b).

is then connected to one of the add ports of the 4x4 MCS and then sent to the WSS. In the experiment, this WSS is replaced by one Waveshaper or attenuator for the emulation of the 1x2 WSS function, which does not affect the results. After transmission over around 30-km single mode fiber, the coherent signal is sent through the opposite connection and process except the use of drop function from the other MCS. The second fiber is employed for the other direction.

The video streaming is successfully demonstrated, and latency measurement is carried out in a ping-pong test with certain packet size and average of a number of packets (200 and 1000 packets). The test is started from back-to-back Ethernet switch connection, then step by step with the addition of fiber, muxponder, and then WSS and MCS in the link. The results are shown in Fig.2. (b). It is clearly seen that the Ethernet switch and fiber propagation dominate the latency contribution This is a switch under no congestion condition. The difference in an actual field deployment should be much bigger. The MCS only introduces less than 2μs and the muxponder, including aggregation/disaggregation and coherent modulation/detection/processing, shows very low-latency performance.

## 4. Full-Duplex Coherent Operation

In order to operate on a single fiber, the typical approach has been to use two separate lasers in a single transceiver, allowing it to transmit and receive on different wavelengths. However, adding a second laser adds significant cost, as well as increasing power consumption, operational complexity, and transceiver footprint. To achieve the objective of keeping cost down while using a single fiber, an alternative method is to employ full-duplex coherent optics as shown in Fig. 3, which is different from Fig. 2 with two fibers in the ring. In this approach, an optical circulator is added to each end of the coherent link in a special configuration. The circulator is a low-cost, passive, directional device for rerouting the optical path in different directions. This permits the coherent transceiver to transmit and receive using the same wavelength (and therefore using a single laser) over a single fiber in both directions simultaneously. Unlike backbone and metropolitan coherent optical networks, edge/distribution networks don't require multiple directional optical amplifiers in a cascade optical link. When dealing with coherent signals, we have a much higher optical signal-to-noise ratio (OSNR) and power sensitivity and higher tolerance to impairments from the spontaneous Rayleigh backscattering (continuous reflection) and Fresnel reflection (discrete reflections), than intensity-modulated systems [6]. In addition, the threshold of the stimulated Brillouin scattering (SBS) nonlinear effect is much suppressed because of the nature of phase-modulated signals on the reduction of optical carrier power and the increase of effective linewidth.

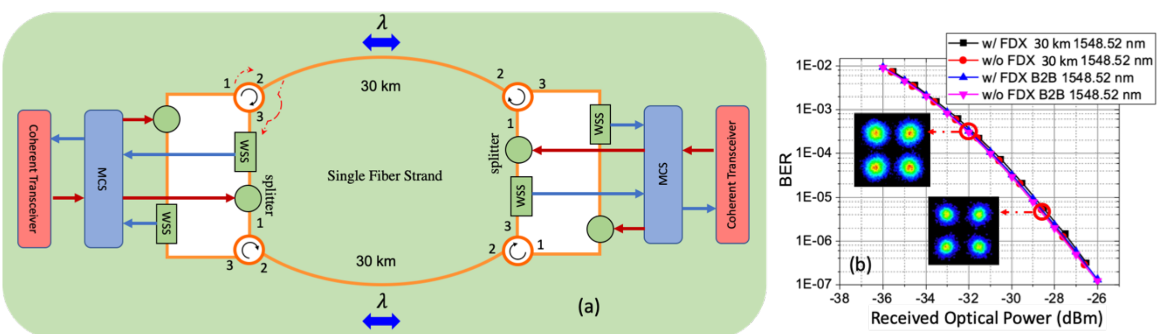


Fig. 3. Full-duplex system setup (a) and experimental results (b), BER: bit error rate.

Fig. 3 (b) shows the results for 30-km fiber transmission distances with coherent signals on the same wavelength (1548.52 nm) for both directions. Negligible power penalties are observed after 30-km transmission when comparing full-duplex operation with single direction operation.

## 5. Summary

We have presented the new design of consolidated inter-hub architecture with simplified combination of WSS and MCS for offering CDC functions at cable operators evolved optical edge/distribution network. End-to-end video delivery with 2-μs latency from multicast switch and 11-μs latency from interoperable coherent muxponder has been experimentally demonstrated. The experimental results of full-duplex operation show the cable operators an elegant solution to their single-fiber use cases with coherent optical systems.

## 6. References

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