

Field Trial of Coexistence and Simultaneous Switching of Real-time Fiber Sensing and 400GbE Supporting DCI and 5G Mobile Services

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Abstract: Coexistence of real-time constant-amplitude distributed acoustic sensing (DAS) and 400GbE signals is verified by field trial over metro fibers, demonstrating no QoT impact during co-propagation and supporting preemptive DAS-informed optical path switching before link failure. © 2022 The Author(s)

1. Introduction

Recent advances in optical fiber sensing has enabled telecom network operators to monitor their fiber infrastructure while creating new revenue streams in data center interconnect (DCI), public safety, and smart city applications [1, 2]. As using dedicated fibers for sensing may be undesirable for operators whose fiber networks are close to fully utilized for dense wavelength-division multiplexing (DWDM) transmission, it is also possible that common optical functions, such as optical switching, can be shared between sensing and communication equipment for cost reduction. To achieve that goal, it is crucial to study the coexistence of sensing and data transmission on the same DWDM network regarding the impact to quality of transmission (QoT) [3], such as pre/post-FEC bit error rate (BER). Furthermore, an integrated platform with joint sensing and communication capabilities allows the sensing system to provide advance warnings to the network management system and to facilitate optical switching to the backup route in the event of fiber cuts.

In this paper, we report field trial results investigating the co-propagation of distributed acoustic sensing (DAS), coherent 400GbE, and analog radio-over-fiber (ARoF) signals using field-deployed dark fibers in a dense metro area using the city-scale PAWR COSMOS testbed [4] deployed in Manhattan. The ARoF provides direct transmission of analog wideband radio signals over the same fiber route to support centralized RF resources for 5G/6G fronthaul. We show that the constant-amplitude DAS operating at optimal power levels has minimal impact on the coherent 400GbE QoT in real-time. We also demonstrate a use case of DAS-informed preemptive optical switching of a 400GbE signal to a backup route as the DAS identified abnormal events indicating possible outage on the original fiber link.

2. Field Trial Setup

Fig. 1 shows the field trial setup using the COSMOS testbed [4], which is a city-scale programmable testbed deployed in Harlem, NYC, to facilitate research and experimentation with advanced wireless and optical technologies in a dense urban environment. We leverage COSMOS' programmable optical components including optical space switches, Lumentum ROADM-20 units, and Manhattan dark fiber, as well as compute and wireless components including servers, data switches, and software-defined radios (SDRs). Different optical network topologies are realized using COSMOS' programmable optical components with lab fiber spools and two dark fiber routes, including a 32 km loopback route via 32 Avenue of the Americas (32AoA), provided by ZenFi via the PAWR consortium, and an 8 km loopback route via the City College of New York (CCNY), provided by NYC and Crown Castle. The 400GbE whitebox transponder, which is compliant with Telecom Infra Project's (TIP's) Phoenix requirements, consists of the NEC Network Operating System (based on the open-source Goldstone software) running on Wistron's Galileo Flex-T hardware with Lumentum 400GbE CFP2-DCO pluggables. The transponder supports data rates of 100G–400G via flexible modulation formats and baud rates. We select 400GbE transmission with dual-polarization 16QAM (DP-16QAM) in this field trial. The coherent 400GbE channel carries heterogeneous data services aggregated via the Galileo Flex-T whitebox and the COSMOS data switch, including parallel TCP traffic for DCI (`srv1/srv2`), digital radio baseband signals for wideband spectrum monitoring (`srv1/sdr2/sdr3`), and 100 GbE traffic. The ARoF channel between `sdr1` and a remote antenna carries a 100 MHz 5G new radio (NR) physical downlink shared channel (PDSCH) signal with 64QAM modulation. The ARoF signal is modulated using a linear electro-absorption modulator (Optilab LT-12-E-M) and detected using an amplified PIN photodiode receiver (Optilab PR-12-B-M).

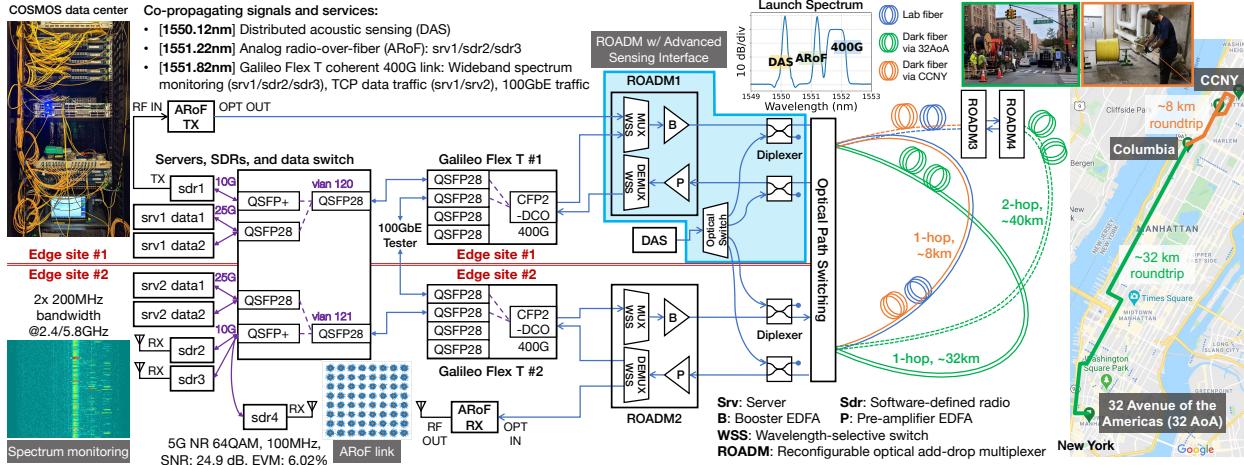


Fig. 1: Experimental setup of the field trial of co-propagating DAS, coherent 400GbE, and ARoF signals using the PAWR COSMOS testbed deployed in Harlem, NYC. Two edge sites, each equipped with a Galileo Flex-T whitebox and a 400GbE CFP2-DCO pluggable, a ROADM unit, and a DAS interrogator, can be connected through different routes via optical path switching.

We employ the ROADM units with an advanced sensing interface to multiplex/de-multiplex the 400GbE coherent signal centered at 193.1875 THz (1551.82 nm), the ARoF signal centered at 193.2625 THz (1551.22 nm), and the DAS signal centered at 193.4 THz (1550.12 nm). The sensing interface on the advanced ROADM architecture enables simultaneous switching for communication and sensing. The interface utilizes low loss optical diplexers (<0.4 dB) at the ROADM input/output line ports in conjunction with an optical switch (see Fig. 1). The diplexer's passband is centered at 193.4 THz (1550.12 nm) with 100 GHz bandwidth for DAS operation. The interface also allows routing of the DAS signal in the same or opposite direction as the DWDM channels for performance testing on the 400GbE QoT. Two different DAS technologies were tested: one using the conventional pulse interrogation scheme with 100 ns pulse width (*pulse-based DAS*) [2], and the other using chirp-pulse interrogation to maintain constant signal amplitude (*constant-amplitude DAS*) [5]. Both DAS systems were implemented in real-time on field-programmable gate arrays (FPGA) with coherent optical receiver frontends for dual-polarization coherent detection. The chirp-pulse DAS has a chirp pulse width of 50 μ s with a designed coding gain of 27 dB. Both systems were configured to have an interrogation frame rate of 2 kHz to support monitoring of up to \sim 50 km fiber distance for metro networks.

3. Experimental Results

We first consider a single 400GbE coherent channel with the channel launch power optimized at +3 dBm. Fig. 2(a) shows the measured pre-FEC BER of the 400GbE signal for receiver OSNR-sweep measurements in both directions on the 2-hop fiber route (32 km and 8 km), with different ROADM WSS channel width (75/100 GHz) and FEC modes (OFEC/HG-FEC provided by the whitebox transponder). Overall, HG-FEC achieves better OSNR tolerance than OFEC, with an OSNR limit measured at 22.1 dB and 23.2 dB, respectively. The pre-FEC BER exhibits minimal difference due to ROADM WSS filtering effect when the 400GbE signal is sent on 75/100 GHz channels. In the rest of the coexistence experiments, we apply HG-FEC and use 75 GHz channel width for the 400GbE signal.

Using the field trial setup, we investigate the system performance when three signals co-propagate over the 32 km fiber route via 32AoA (see inset of Fig. 1 for the launch spectrum). Fig. 2(b) shows the measured pre-FEC BER when the DAS channel propagates in the *same direction* as the 400GbE coherent channel, where the launch power of the DAS interrogation signal is swept while the 400GbE coherent channel power is kept constant at +3 dBm. Due to different DAS interrogation waveforms, pulse-based DAS operates optimally at a higher peak power (+15 dBm) compared to that of the constant-amplitude DAS (+3 dBm) at longer fiber distances. Note that the average power of the pulse-based DAS is much lower with a pulse duty cycle ratio of 37 dB. The results show that although the pre-FEC BER remains unchanged at 7.3×10^{-4} with increased power of the pulse-based DAS, the 400GbE starts to exhibit uncorrected errors and observable post-FEC BER when the average power of the pulse-based DAS power exceeds -23.4 dBm, which is still below its optimal operation region. Under such conditions, the 400GbE client traffic is effectively shut down. Due to the low frame rate and short burst nature of pulse-based DAS, the additional errors from cross-phase modulation (XPM) are not reflected in the pre-FEC BER, but could still cause service interruptions as the burst errors are insufficiently randomized by the FEC interleaver. On the contrary, we are able to increase the power of constant-amplitude DAS up to +9 dBm without incurring any post-FEC bit errors, which is well beyond its optimal operation region. When the DAS is switched to the *counter-propagation direction*, we observe no impact from both DAS systems on the 400GbE

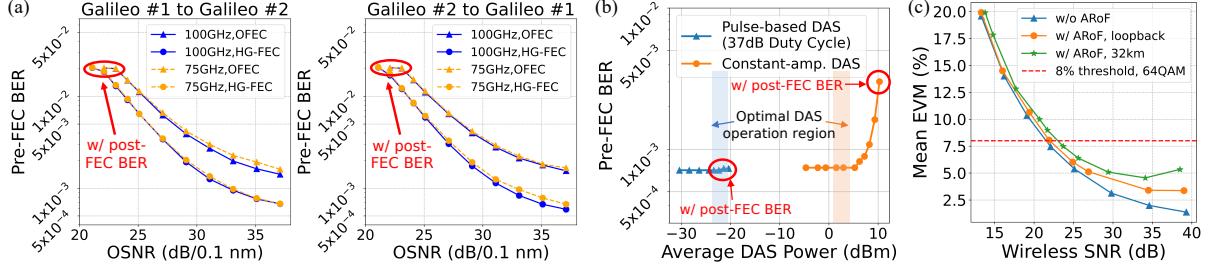


Fig. 2: (a) Coherent 400GbE QoT: pre-FEC BER with different ROADM channel widths and FEC modes. (b) Impact of two DAS interrogators on the 400GbE QoT. Non-circled points indicate a zero post-FEC BER. (c) EVM of ARoF-based 5G NR signal.

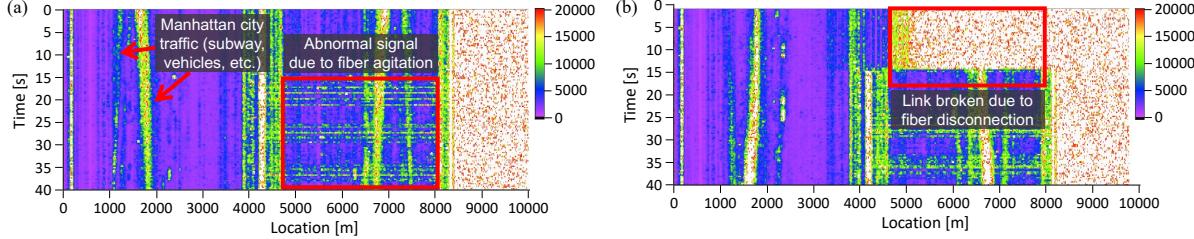


Fig. 3: DAS waterfall plots on the 8 km fiber route via CCNY before and after patch panel disconnection.

QoT for both pre-FEC and post-FEC BER. On the 8 km route, we also observe no impact from both DAS in either propagation direction, likely due to the limited nonlinear interactions on the short fiber distance. Fig. 2(c) shows the measured mean error vector magnitude (EVM) of the co-propagating ARoF signal, where the 8% threshold is the 3GPP EVM requirement for 64QAM. Slight degradation of the EVM is observed when the ARoF signal is sent over the 32 km route compared to scenarios where the ARoF TX and RX are connected using a short loopback fiber or without using ARoF. In addition, no impact of the ARoF signal on the coherent 400GbE signal QoT is observed as we sweep the launch power of the ARoF up to +10 dBm while keeping a constant launch power on the 400GbE signal.

The co-propagating DAS monitoring signal can provide protection of the coherent 400GbE channel: by detecting abnormal events signatures preceding a link outage, alerts can be triggered for preemptive optical path switching. We demonstrate such a scenario when the constant-amplitude DAS picks up signals indicating unauthorized fiber access on the 8 km fiber route (see Fig. 3(a)). The “waterfall plot” shows the vibration strength as a function of time (y-axis) and fiber location (x-axis) with a spatial resolution of 10 meters. The vibration signal beyond the fiber end (> 8.4 km) is saturated as signal extraction relies on differential optical phase interferometry and low signal amplitudes create large phase fluctuations. The 8 km fiber route is formed by a loopback cable at CCNY (see Fig. 1), thus the waterfall plot is symmetric around the loopback point at 4.2 km. When the loopback cable on the patch panel was manually agitated, bright horizontal lines are observed as the fiber movement causes frequency shifts of the DAS chirp pulse. The signature is clearly different than other large vibration signals picked up by the DAS, such as Manhattan subways (at 1.7 km) and server room equipment vibrations (at 4.2 km). Therefore, it can be reported to the network management system as an advance warning for imminent link outage. In our demonstration, upon the detection of the abnormal signal and before the 8 km fiber link is broken (see Fig. 3(b)), the management system can optically switch the 400GbE signal to the backup 32 km route via 32AoA with a switching time of ~ 50 ms.

4. Conclusions

We demonstrated simultaneous switching of coherent 400GbE, DAS, and ARoF channels using a ROADM unit with an advanced sensing interface. The coexistence of 400GbE and DAS signals was verified using a commercial Galileo Flex-T whitebox transponder and a real-time constant-amplitude DAS over metro fibers. We successfully demonstrated switching of a 400GbE signal to a backup route after identifying abnormal patterns indicating imminent fiber outage.

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