Real-Time Demonstration of 600 Gb/s DP-64QAM Self-Homodyne Coherent Bi-Direction Transmission with Un-Cooled DFB Laser

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Abstract: We report first successful real-time self-homodyne coherent bi-direction transmission demonstration with 600-Gb/s DP-64QAM under un-cooled ~7-MHz linewidth DFB laser. A novel coherent receiver is proposed to achieve automatic stabilization against polarization fluctuations of received LO.

OCIS codes: (060.1660) Coherent communications; (060.2330) Fiber optics communications

1. Introduction

Increasing growth of data center traffic has become the major portion of nowadays global Internet Protocol (IP) traffic. It requires the use of high-capacity optical interfaces for inter-/intra- datacenter interconnects and networks (DCI&DCN), hence 800 GE or even 1.6 TbE is anticipated [1]. Due to its simplicity and low cost, intensity modulation and direct-detection (IMDD) system with coarse wavelength division multiplexing (CWDM) is still preferred in nowadays short reach applications for DCI&DCN [2]. However, limited by the number of used wavelengths and bandwidth densities, it is hard to cope with the endless increase of data rate requirements of data centers. Traditional coherent detection used in metro and long haul, with higher receiver sensitivity and spectral efficiency, provides a robust and scalable solution for short reach systems in data center. Nonetheless, it is still widely regarded as too expensive and power consuming for DCI&DCN due to the demand of narrow-linewidth lasers and complex digital signal processing (DSP) algorithms. Thus, several 'coherent lite' schemes have been proposed to reduce the power consumption and transceiver cost [3-7]. Among them, the self-homodyne coherent detection (SHCD) has recently been considered as the most potential candidate for data center applications. The main concept of SHCD system is to send the modulated signal and a copy of tone as local oscillator (LO) originating by the same laser from transmitter (TX) to receiver (RX) for coherent reception. It can minimize the impact of laser phase noise and omit the frequency offset, thus allows the use of un-cooled lasers with large linewidth and simplifies the DSP algorithms. The benefits have been verified in [5-7] by simulation and offline experiment investigations. However, one of the key practical considerations, the automatic polarization tracking to compensate for the polarization wandering of received LO, haven't been fully studied yet.

In this paper, we report the first successful real-time demonstrations of SHCD systems in bi-direction (BiDi) transmission with 400G DP-16QAM and 600G DP-64QAM. A LO polarization tracking device based on compact silicon photonic (SiP) chip, with low costs and power consumptions, is proposed with trackable polarization speed up to 300 rad/s. Such speed can satisfy most of the short reach scenarios in data center application due to the short transmission distance and the relative stable environment variation [8]. In addition, we perform a detailed experimental parametric study of the proposed system in which various system parameters are investigated such as laser linewidth, mismatch length, reach, and laser power. Our results verify that DP-64QAM systems can be realized using low-cost distributed feedback laser (DFB) with linewidths up to 7MHz. What's more, our SHCD BiDi line interfaces can reach to ~40km and ~5km transmission distance (standard G. 652 fiber) without EDFA amplification for 400G DP-16QAM and 600G DP-64QAM respectively.

2. Principle and real time experiment setup of SHCD BiDi transmission system

Figure 1(a) shows the architecture of the proposed SHCD BiDi transceivers at both ends of the link. For each transceiver, the TX sends the modulated signal and a copy of the tone (for replacing the traditional LO at the receiver) from the same laser to the remote Rx through different lanes of a full-duplex fiber. Ideally, there is no longer need for frequency offset (FO) and carrier phase estimation (CPE) since the transmitted LO has the same central frequency and reference phase of the transmitted signal. Thus un-cooled operation of a DFB laser with large linewidth becomes possible in coherent detection which provides cost and power consumption saving for the transceiver. Meanwhile, the full-duplex fiber can be used as bidirectional fibers achieved via different wavelength laser at each transceiver side and four CWDM C1 to C4 as shown in Fig. 1(a). Note that such bidirectional transmission results in no penalty if λ1 and λ2 are sufficiently spaced to avoid any backscattering effects.

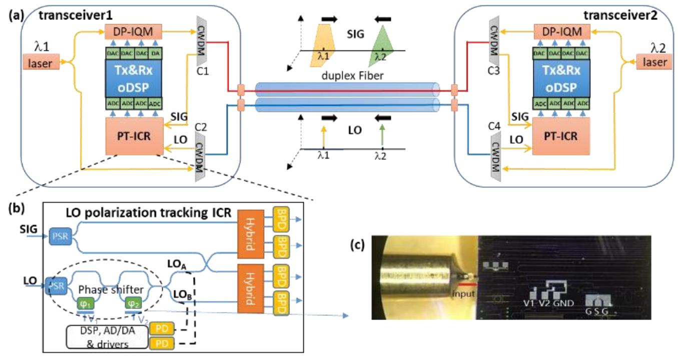

Fig. 1(a) General schematic of the proposed SHCD BiDi transmission structure; (b) LO polarization tracking integrated coherent receiver (PT-ICR) structure; (c) the architecture of polarization tracking function part in PT-ICR implemented in SiP chip

A key practical issue for this system is to avoid the received LO polarization fading to ensure tone-signal beating on both state of polarizations at the coherent receiver. We propose a scheme named as LO polarization tracking integrated coherent receiver (PT-ICR) which is shown as Fig. 1(b). It is similar to the traditional coherent receiver with two polarization shift rotator (PSR), 2 × 8 90° optical hybrid and four balanced photodiodes (BPD), but has an extra photonic integrated circuit (made by several stages of optical phase shifters and 2x2 symmetric couplers) after the LO port. Here, the different stage phase shifters are controlled depending on the state of polarization of the received LO to simply produce equal tone powers at the two outputs (LO_A and LO_B) of the end 3 dB coupler. Such structure has the ability to provide an endless polarization tracking when driven by a suitable controlling algorithm. What's more, the cascade of variable phase shifters and fixed 2x2 couplers can easily be integrated with the reset components of PT-ICR by SiP. Fig. 1(c) shows the architecture of polarization tracking function part in our PT-ICR device implemented in a very compact SiP chip, whose phase shift is thermally tuned by changing the voltage applied to the heater. The thermal phase shifters provide a small insertion loss (<0.3dB) and a limit phase tuning speed around 20 kHz.

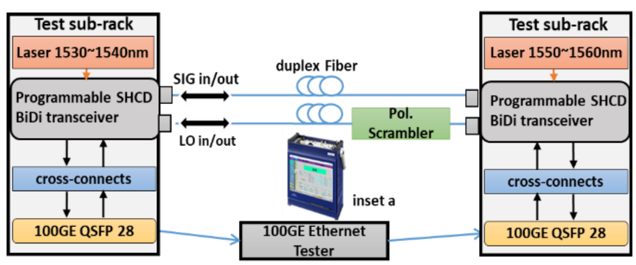

Fig. 2. Real time SHCD BiDi experimental setup

We packed the PT-ICR into our real time multi-format flex-rate coherent transceiver supporting 400G DP-16QAM and 600G DP-64QAM to build the prototype SHCD BiDi transceiver. The FO and CPE functions in the transceiver oDSP chip can be configured to be closed for saving the power consumption. Different types of lasers are externally injected in the transceiver to compare the performance. Fig. 2 shows the configuration for real-time SHCD BiDi demonstration in laboratory network, where the line interfaces housed in a test sub-rack. 100GE client signal from 100G Ethernet tester (inset a) is mapped over the 400/600G optical signal via the 100GE QSFP28 interface and cross-connects to verify end to end performance. A polarization scrambler is set on the LO link for emulating the effects of fast polarization variations.

3. Measurement Results and Discussions

We first compare the received optical power (ROP) performances of 400G DP-16QAM and 600G DP-64QAM in back-to-back (B2B) under three types of lasers with different linewidth (LW), as shown in Fig. 3(a). For both 400G 16QAM and 600G DP-64QAM, the systems using larger linewidth DFB do not introduce distinguished penalty than that of narrow linewidth ECL system, only a higher pre-FEC BER floor is witnessed for the 7MHz linewidth DFB system of 400G 16QAM. Note that the conventional intradyne coherent detection systems cannot work under the lasers with such large linewidth. In Fig. 3(b), we investigate the effect of the mismatch of the signal and the LO transmission paths on the system performance under different DFB linewidth. Here, the CPE function in oDSP chip is opened to against the phase noise caused by the mismatch. It can be seen that the performance becomes more sensitive to mismatch as the increasing of linewidth as well as the modulation format. With 7MHz DFB laser, the 600G 64QAM system only tolerates 20 cm of mismatch. However, such mismatch tolerance of 20 cm is more than sufficient for an actual full-duplex fiber where both the signal and tone fiber pair are in one cable. Fig. 3(c) shows the transmission distance of our SHCD BiDi line card under different laser power without EDFA amplification. For a typical 16dBm 7MHz DFB laser, with the SIG and LO ports (shown in Fig. 2) output powers around -10dBm and 12dBm, the 600G DP-64QAM can reach to ~5km, and ~5.9km for G. 652 and G.654 fiber respectively. While, the 400G DP-16QAM systems extend the transmission distance to ~40 km (G. 652) and ~47 km (G.654).

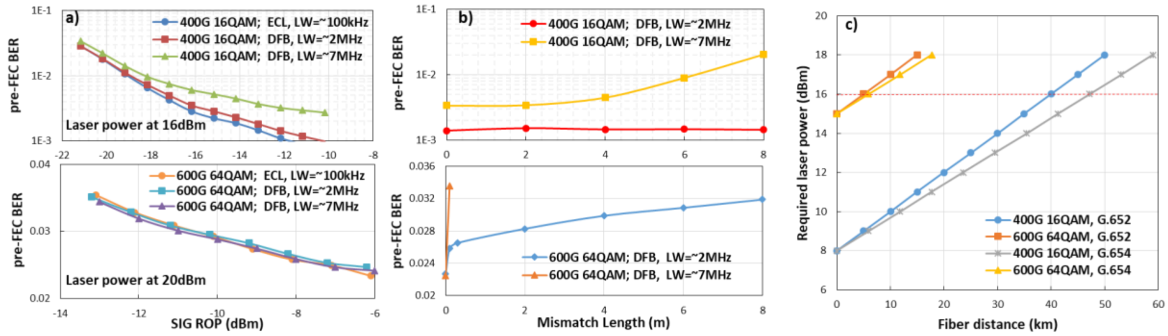

Fig. 3. SHCD BiDi experimental results of 400G DP-16QAM and 600G DP-64QAM showing (a) pre-FEC BER vs. signal ROP under a fixed LO ROP in B2B for three different lasers, (b) pre-FEC BER versus mismatch length between tone and signal lanes for 2 types of DFB laser in different LW, (c) required laser power vs. transmission distance for 2 types of fiber (G.652 and G.654).

To investigate the polarization tracking ability of our PT-ICR, we programmed the polarization scrambler (in Fig. 2) to cyclically rotate one of its internal waveplates at speed gradually increased up to 1500 rad/s, generating different traces on the Poincare sphere (shown in the inset of Fig. 4(a)). The pre-FEC BER performance under different polarization rotation speeds of LO input (shown in Fig. 4(a)) shows that there is negligible penalty in the performance up to 300 rad/s. Here, BER is degraded by the fact that the two outputs (LO_A and LO_B in Fig. 2) starts having significant fluctuations. In a second set of experiments, we programmed the polarization scrambler to generate random polarization movements (as the insets of Fig. 4(b)) at 300 rad/s over the Poincare sphere, then we continuously measured for two hours the resulting pre-FEC BER. Fig. 4(b) shows that the pre-FEC BER consistently remained well. Furthermore, we have verified that the client achieved error-free transmission over 24 hours under such random polarization movements (shown as Fig. 4(c)).

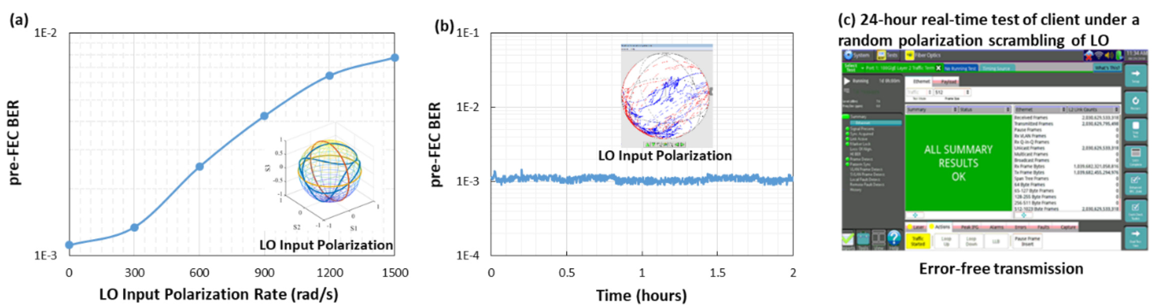

Fig. 4. a) BER vs. polarization rotation speed of received LO for PT-ICR; b) long term BER measurement at 300 rad/s random polarizations rotation of received LO; c) An Ethernet tester report showing error free over 24 hours.

4. Summary

In this paper, we successfully demonstrate a real-time 600Gb/s DP-64QAM SHCD BiDi transmission with 7MHz un-cooled DFB laser. The proposed PT-ICR combated the polarization fluctuation of LO after transmission, which is the key implementation issue of SHCD BiDi system. Our verification paves the way to utilize this 'coherent lite' technique practically for the next generation DCI&DCN applications.

5. References

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