Complementary Polarization-diversity Self-Coherent Homodyne Receiver with Rapid Polarization Tracking for Remote LO

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Abstract: We propose a complementary polarization-diversity coherent receiver (C-PDCR) based on complementary polarization detection. The proposed C-PDCR features rapid polarization tracking for remote LO using electronic DSP. The robustness is verified by a 1.08-Tb/s dual-polarization PCS-256QAM signal with up to 314-Krad/s polarization tracking speed. © 2022 The Author(s)

1. Introduction

800-Gb/s and 1.6-Tb/s switch interface speeds are envisioned to be the next target in the Ethernet roadmap [1]. To achieve such data rate requirements, multi-channel parallel optics based on intensity modulation and direct detection (IMDD) are still preferred nowadays for short-reach applications [2]. However, limited by the required number of wavelengths and component bandwidth, IMDD based parallel transmission systems are hard to scale with rapid capacity increase. Therefore, there has been renewed interest in spectrally efficient coherent transmission systems to minimize the amount of parallel hardware and realize those next-generation Ethernet transports. However, the classical coherent detection systems are widely considered as too costly and power-intensive for short-reach optical interconnects due to the need for expensive high-stable lasers. Most recently, as a compromising solution, self-coherent homodyne detection systems have been investigated to both improve the capacity scalability and simplify the DSP complexity [3]. In such a system, the dual-polarization (DP) signals and self-coherent local oscillator (LO) originating from the same laser source are co-propagated over a duplex fiber. However, the fast evolution of the state of polarization (SOP) of remotely delivered LO becomes problematic for the polarization-diversity coherent receiver (PDCR) [4]. To address the occurrences of arbitrarily varying SOP and polarization fading of the received remote LO, the automatic/adaptive polarization controller (APC) is needed for LO in the conventional PDCR. However, the APC generally requires complicated device design and algorithm control to achieve transparent polarization transformation in an endless manner referred to as reset-free. Most importantly, the polarization tracking speed of the engineered APC is only up to a few hundred rad/s [5], which may not be sufficient for the links that undergo fast mechanical disturbances. A hybrid Stokes vector receiver and single-polarization coherent receiver has been proposed as a hybrid PDCR without optical polarization control for the remotely delivered LO [6]. But this approach requires a polarization-diversity 90-degree optical hybrid which is difficult to implement in silicon photonic integrated circuits.

In this paper, we propose a C-PDCR by introducing a third complementary coherent receiver for rapid polarization tracking of remote LO based on electronic DSP. To demonstrate the robustness of our proposed C-PDCR, a 90-Gbaud probabilistic constellation shaped (PCS) 256-QAM DP signals with 1.08-Tb/s source rate is successfully recovered under rapid LO polarization rotation rate up to 314 Krad/s featuring 1047-fold tracking speed improvement.

2. Principle of proposed C-PDCR

To combat the random polarization wandering of the remotely delivered LO, the conventional PDCR consists of an APC for the remote LO has been widely investigated, which is shown in Fig. 1(a). Distinguished from the conventional

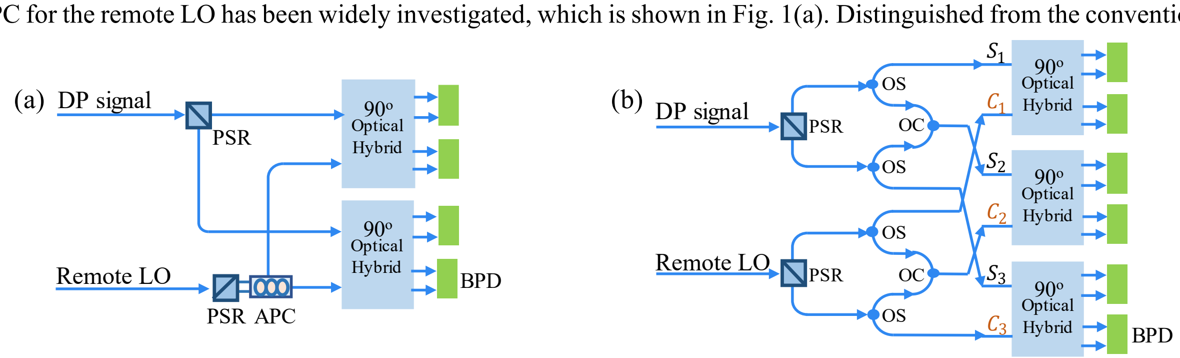

Fig. 1: Configuration of (a) conventional PDCR using an APC for remote LO and (b) proposed C-PDCR without any optical polarization control for remote LO. PSR: polarization splitter/rotator. OC/OS: optical coupler/splitter. BPD: balanced PD.

PDCR, we propose a C-PDCR without any optical polarization control for the remote LO, which is illustrated in Fig. 1(b). In addition to the two 90-degree optical hybrids in the conventional PDCR, the proposed C-PDCR comprises the third coherent receiver to provide complementary-polarization diversity (CPD). In the proposed C-PDCR, the received DP signal and remote LO are all first decomposed into two branches by using the polarization splitter/rotators (PSRs). The two branches of either the DP signal or remote LO are optically combined to get a complementary polarization output using optical splitters/couplers only. By using the 90-degree optical hybrids, the three enhanced polarization outputs of the DP signal beat with the three corresponding outputs of the remote LO. Compared with the conventional PDCR, our proposed C-PDCR requires one more 90-degree optical hybrid including two balanced photodetectors. However, along with the advent of advanced silicon photonics integration, the transceiver cost difference would be marginal between the two receiver schemes as presented in Fig. 1. Moreover, the unique advantage of the proposed C-PDCR scheme is without optical polarization control and no polarization fading issue for remote LO. Let $S = [S_X, S_Y]$ and $C = [C_X, C_Y]$ ($|C_X|^2 + |C_Y|^2 \neq 0$) that denote the DP signal and remote LO electrical fields after the PSRs, respectively. Ignoring some trivial constants and phase delays, the DP signal and remote LO fed into the three 90-degree optical hybrids are $[S_1, S_2, S_3] = [S_X, S_X + S_Y, S_Y]$ and $[C_1, C_2, C_3] = [C_X, C_X + C_Y, C_Y]$, respectively. When the polarization fading effect occurs, one polarization tributary $C_1/\, C_3$ of the remote LO could be zero. Note that the two polarization tributaries C_1 and C_3 could not be in fading simultaneously due to the bounded constraint $|C_X|^2 + |C_Y|^2 \neq 0$. Under such circumstances, the complementary polarization output C_2 could regenerate the faded polarization tributary. When the complementary polarization output C_2 has fading, the two polarization tributaries C_1 and C_3 preserve the LO power and provide polarization-diversity detection. Therefore, our proposed C-PDCR scheme is fundamentally resilient against arbitrary input SOP of the remote LO. From the three optical hybrids, we can get the electrical output $[S_1 C_1^*, S_2 C_2^*, S_3 C_3^*]$, which contains a linear combination of the DP signal. To perform the polarization demultiplexing, namely, polarization tracking, the 3×2 MIMO in Jones pace is required to retrieve the transmitted DP signal. Compared with the standard DSP in the conventional PDCR, the only small modification is the MIMO and most of the legacy coherent DSP stack is reusable.

3. Experimental setup

To validate our proposed C-PDCR, a 1.08-Tb/s transmission experiment is conducted. The experimental setup is shown in Fig. 2. The laser source with 15-kHz linewidth is employed for the generation of both DP signal and self-coherent LO. The transmitter DSP for generating a 90-Gbaud signal is shown in inset (i). The DP signal is produced by a polarization emulator. The optical spectrum of the generated DP signal is shown in inset (ii). For the self-coherent remote LO, to investigate the polarization tracking speed of our proposed PDCR, we assemble a polarization scrambler

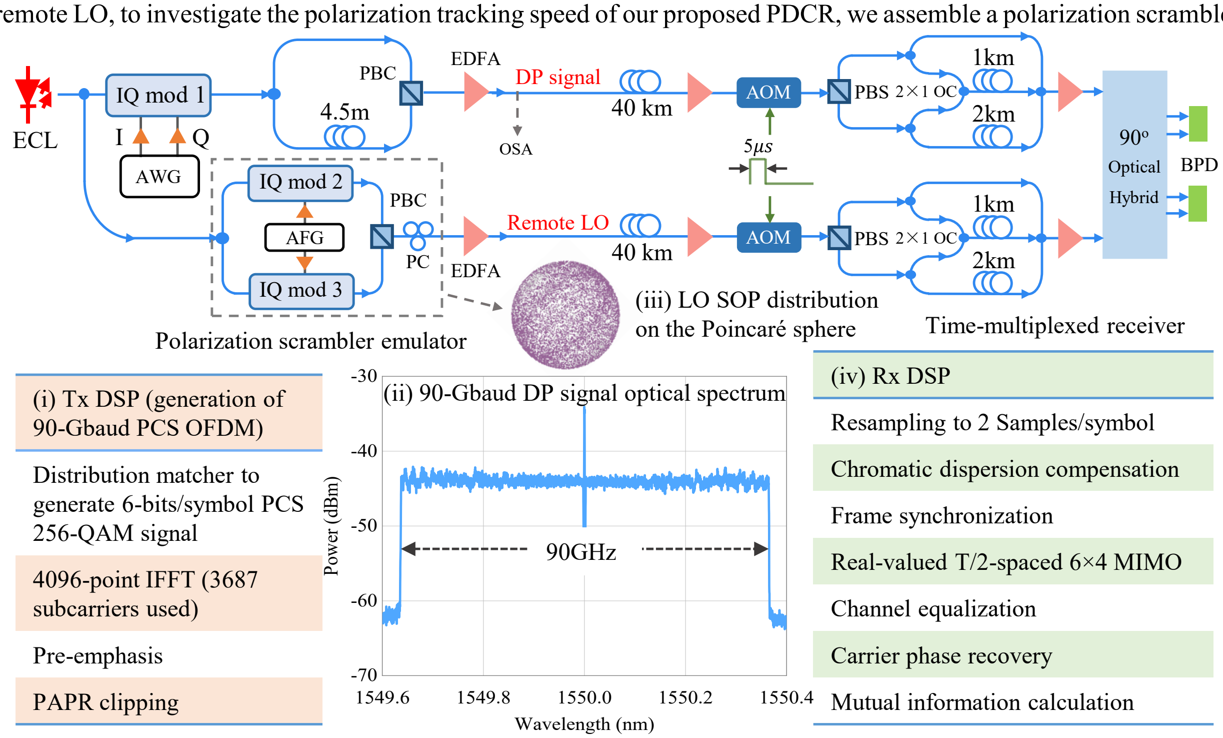

Fig. 2: Experimental setup. IQ mod: IQ modulator. AWG/AFG: arbitrary waveform/function generator. PC: polarization controller. PBS/PBC: polarization beam splitter/combiner. OSA: optical spectrum analyzer. AOM: acoustic-optic modulator.

to depolarize the remote LO before launched into the optical fiber. In the emulated polarization scrambler [7], the two low-speed IQ modulators are driven by two radio signals $cos(2\pi ft)$ and $sin(2\pi ft)$, respectively, where f is polarization rotation frequency in Jones space. The trajectory of the SOP of LO on the Poincaré sphere will be a circle with a rotation frequency of $2f$ in Stokes space. To cover the whole Poincaré sphere, the manually tuned polarization controller (PC) is deployed and the transmission fiber will also offer randomness. The simulated SOP distribution on the Poincaré sphere by the emulated polarization scrambler is shown in inset (iii). At the receiver side, a time-multiplexed receiver configuration using AOMs is implemented to save the number of needed analog-to-digital converters (ADCs) and BPDs (this configuration is not needed in a field receiver). The received electrical signals from the two BPDs are sampled by a 160-Gsa/s oscilloscope. The receiver-side DSP for DP signal recovery is shown in Fig. 2(iv). Generalized mutual information (GMI) [8] is used as the metric of performance evaluation.

4. Results and discussions

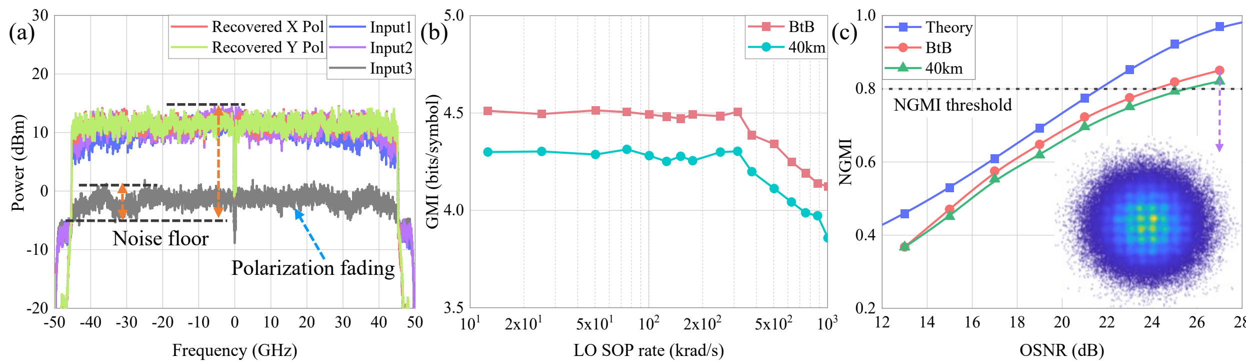

Fig. 3: (a) Electrical spectra before/after MIMO when polarization fading occurs. (b) GMI performance as a function of LO SOP rotation speed at the 25-dB OSNR. (c) OSNR sensitivity of the proposed C-PDCR with 1.08-Tb/s data rate. BtB: back-to-back.

To reveal the effectiveness of our proposed C-PDCR scheme using remote LO for combating the polarization fading issue, we compare the electrical spectrums before/after the MIMO as shown in Fig. 3(a). Particularly, we select an SOP when the polarization fading occurs. As illustrated by the curves of MIMO inputs, the power density of one input approaches the noise floor. However, the other two inputs have a strong power density without power fading. By the real-valued 6×4 MIMO, the transmitted DP signal is successfully retrieved and verified by their recovered electrical spectra with the nearly same power density. Furthermore, to signify the robustness of our proposed scheme with the capability of fast polarization tracking speed for remote LO, we measured the GMI performance as a function of the LO SOP rotation rate, which is presented in Fig. 3(b). The GMI performance is quite stable with very small fluctuations under the LO SOP rotation rate up to 314 Krad/s in this experiment. This represents more than a 3-order improvement of magnitude in the polarization tracking speed compared to the prior report [5].

The OSNR performance of the proposed C-PDCR scheme with a 1.08-Tb/s raw data rate is presented in Fig. 3(c). We take a normalized GMI (NGMI) threshold of 0.8 using a practical 27.5% soft-decision forward error correction (SD-FEC) overhead [9]. The required OSNR for back-to-back (BtB) and 40-km fiber transmission is 24 and 25 dB, respectively. The 1-dB OSNR sensitivity difference could be attributed to the optical noise-contaminated remote LO from optical amplifiers. Compared with the theoretical NGMI performance by simulation, the OSNR sensitivity gap is 3-4 dB since there is a strong unsuppressed optical carrier in the optical spectrum of the generated DP signal as shown in the inset (ii) of Fig. 2, and the time-multiplexed receiver structure is quite lossy and noisy. Excluding the FEC overhead [10], the achieved net data rate is 769.4 Gb/s in this experiment.

5. Conclusions

We have proposed and demonstrated a novel polarization-diversity self-coherent homodyne receiver based on complementary polarization detection with the capability of fast polarization tracking for remote LO. The robustness of our proposed C-PDCR against arbitrary input SOP of LO is verified and demonstrated by a 1.08-Tb/s (net rate 769.4 Gb/s) transmission experiment with 1047-fold polarization tracking speed improvement. The proposed scheme could be a promising candidate for future 800G/1.6T Ethernet interface speeds.

6. References

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