Beyond Mrad/s Polarization Tracking Speed of Complementary Polarization-diversity Coherent Receiver for Remote LO

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Abstract: We demonstrate a complementary polarization-diversity coherent receiver (C-PDCR) to accommodate arbitrarily varying SOP of remotely delivered LO. The polarization tracking speed can reach 1 Mrad/s without performance degradation and exceed 2 Mrad/s with a 1-dB OSNR penalty for a 1.08-Tb/s dual-polarization (DP) PCS-256QAM signal. © 2022 The Author(s)

1. Introduction

Short-reach and metro optical networks are cost-sensitive transmission scenarios due to a large amount of needed optical transceivers while the capacity requirements are ever-increasing driven by many merging Internet applications such as online streaming services. Therefore, the improvements in cost and capacity tradeoff are critical for short-reach optical interconnections. In particular, a cost-effective upgrade in overall data rate over multi-channel parallel optics based on intensity modulation and direct detection (IMDD) would be challenging owing to the limited number of wavelengths and component bandwidth. To achieve Tb/s and beyond data rate requirements, the interest in coherent detection has been boosted by exploring the advanced modulation formats as a means of obtaining high spectral efficiency. Yet, the conventional polarization-diversity coherent receiver (PDCR) may be cost-prohibitive for short-reach applications due to the needing for external narrow-linewidth local oscillator (LO) and high-complexity digital signal processing (DSP). To balance the high performance and low cost, the self-coherent homodyne detection-based systems have been studied recently as a compromising solution of PDCR where the transceiver shares the same laser source in the vicinity of another separate fiber for remote LO [1]. However, the state of polarization (SOP) transients can occur during propagation through fiber owing to electromagnetic and mechanical environment disturbances. In common situations, the SOP varying rate can reach several hundreds of krad/s. In some extreme conditions such as light striking, the transient electromagnetic field will cover the nearby areas for several kilometers, which will introduce Kerr and Faraday effects and cause SOP changing speed exceeding Mrad/s [2]. Therefore, to track the fast and arbitrary evolution of SOP of remote LO, an adaptive/automatic optical polarization controller (APC) has been used for conventional PDCR. Up until now, the engineered reset-free APC is only with few hundreds of rad/s [3], which is obviously not sufficient for the diverse environment. To cope with the fast SOP and avoid the polarization fading issue, we have proposed a hybrid PDCR (H-PDCR) consisting of a Stokes vector receiver and single-polarization coherent receiver [4] as presented in Fig. 1(a). However, the implementation of the silicon photonics integration for this hybrid PDCR is not friendly since it requires a polarization-diversity 90-degree optical hybrid (the top one) and optical couplers. For the sake of ease of photonics integration, we further propose a complementary PDCR (C-PDCR) [5] as shown in Fig. 1(b) by introducing the third 90-degree optical hybrid (the middle one) for complementary polarization detection, which could regenerate the faded polarization tributary (the upper or lower 90-degree optical hybrid). Therefore, our proposed C-PDCR scheme is fundamentally robust against arbitrary input SOP of the remote LO. In paper [5], the robustness of the proposed C-PDCR is experimentally demonstrated by a 90-Gbaud

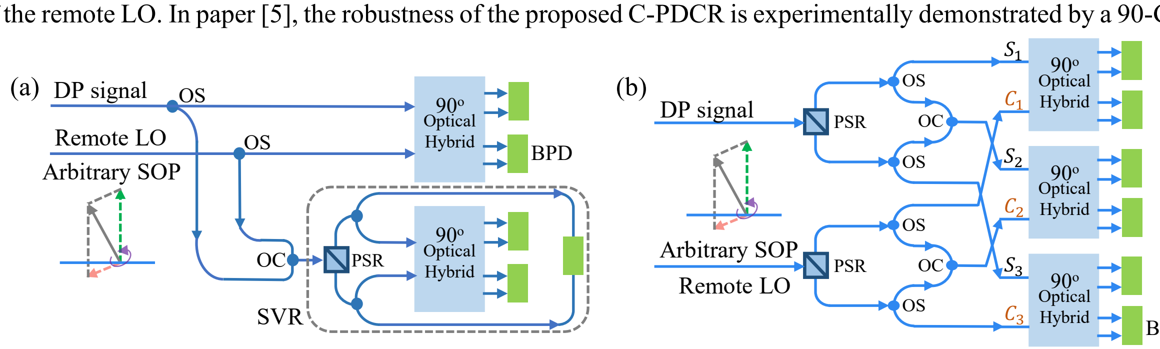

Fig. 1: Schematic of proposed (a) H-PDCR and (b) C-PDCR without any optical polarization control for remotely delivered LO. PSR: polarization splitter/rotator. OC/OS: optical coupler/splitter. SVR: Stokes vector receiver. BPD: balanced photodetector. PoL: polarization. SOP: state of polarization.

DP probabilistic constellation shaped (PCS) 256-QAM signal with up to 314 krad/s LO polarization rotation rate.

In this paper, we further investigate different MIMO algorithms for polarization tracking of the remotely delivered LO in the proposed C-PDCR. By using the recursive least squares (RLS) algorithm for MIMO, the DP PCS 256-QAM signal with 1.08-Tb/s source rate can be successfully recovered under the rapid LO polarization rotation rate of 1 Mrad/s without generalized mutual information (GMI) [6] performance degradation. With a 1-dB OSNR penalty, the polarization tracking speed can exceed 2 Mrad/s.

2. Experimental setup

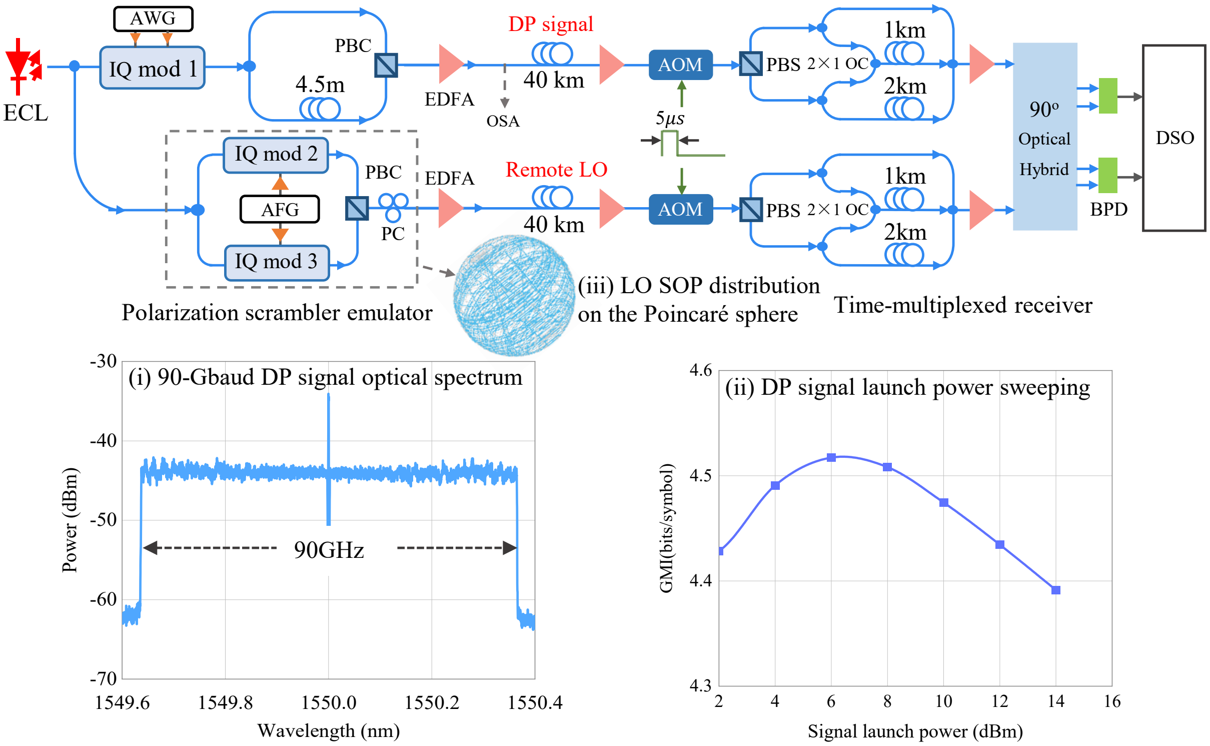

Fig. 2: Experimental setup for C-PDCR. ECL: external cavity laser. IQ mod: IQ modulator. AWG/AFG: arbitrary waveform/function generator. PC: polarization controller. PBS/PBC: polarization beam splitter/combiner. EDFA: Erbium-doped fiber amplifier. OSA: optical spectrum analyzer. AOM: acoustic-optic modulator. DSO: digital sampling oscilloscope.

To investigate the polarization tracking capability of the proposed C-PDCR, an experiment with a 1.08-Tb/s raw data rate is carried out. The experimental setup is shown in Fig. 2. The transmitter and receiver share the same 15kHz-linewidth laser source by using a pair of 40-km fibers. At the transmitter side, a 90-Gbaud DP signal is generated by using a polarization emulator, in which a 4.5-m optical delay line is used for de-correlation. The transmitted signal is formatted in OFDM with a sampling rate of 100 GSa/s. The modulation format for the OFDM signal is PCS 256QAM with an entropy of 6 bits/symbol. The generated signal is pre-emphasized before loading to the AWG to compensate for the band-limiting effects of the used components. The optical spectrum for the DP signal is measured and presented in inset (i) with 90-GHz optical bandwidth. The launch power of the DP signal is also swept and optimized as shown in inset (ii). To depolarize the self-coherent LO with different SOP changing rates, a polarization scrambler is assembled composing of two low-speed IQ modulators and a manually tuned polarization controller. The driving signals for the two IQ modulators are $cos(2\pi f t)$ and $sin(2\pi f t)$, respectively, where f is polarization rotation frequency in Jones space. Therefore, the trajectory of the SOP of remote LO on the Poincaré sphere is a circle with a rotation frequency of $2f$ in Stokes space. Inset (iii) shows the simulated trajectory of the SOP of the remote LO, which covers the whole sphere and verifies the effectiveness of the emulated polarization scrambler. At the receiver side, to save the needed optoelectrical components, a time-multiplexed receiver configuration using AOMs is deployed. The received electrical waveforms are sampled by a 160-GSa/s oscilloscope. To retrieve the transmitted field signals, 6×4 real-valued MIMO is implemented for both channel equalization and polarization tracking.

3. Results and discussions

To exploit the polarization tracking capability of the proposed C-PDCR, three adaptive algorithms, namely least mean squares (LMS), normalized LMS (NLMS), and RLS algorithms are deployed for the 6×4 real-valued MIMO. Since the system has been pushed to its performance limit, there are strong band-limiting effects and IQ imbalance. The

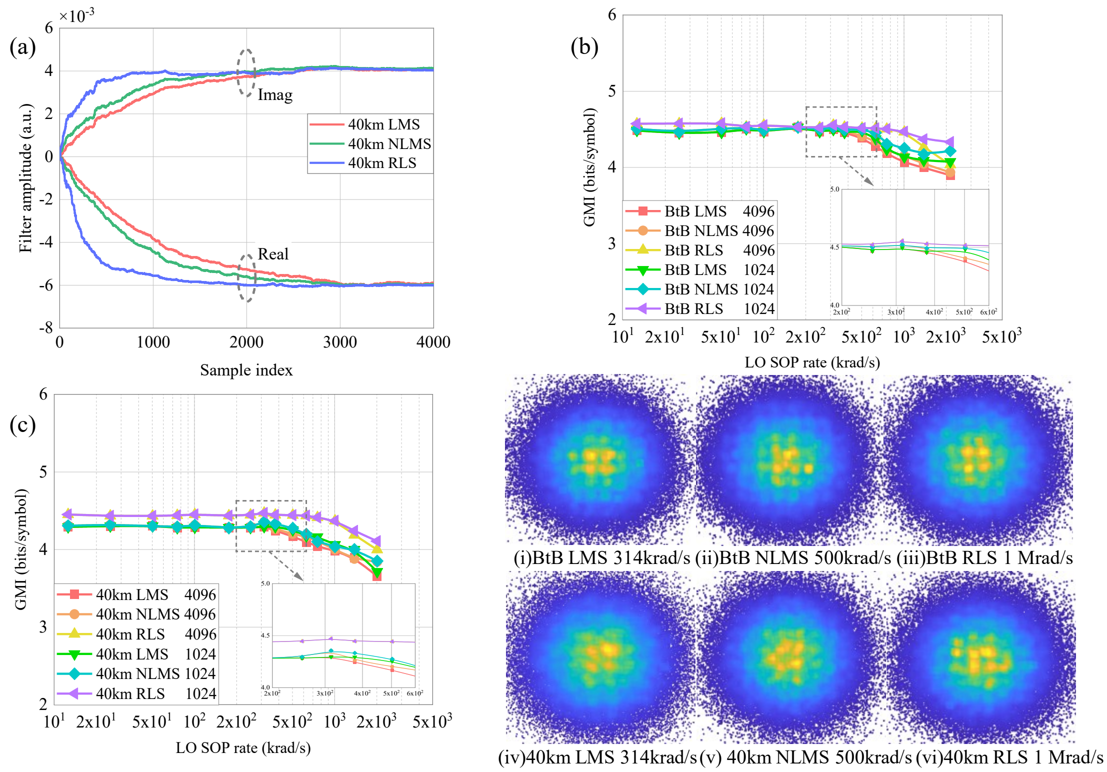

Fig. 3: (a) Convergence rate comparison between different algorithms by observing filter coefficients. GMI performance as a function of LO SOP rotation speed at BtB (b) and 40 km (c) under 25-dB OSNR by using different algorithms with coefficients updated after a different number of symbols for MIMO. Insets show the recovered PCS 256-QAM constellations with coefficients updated once every 4096 symbols.

implemented 6×4 real-valued MIMO has a total of 2184 coefficients. The step size for different algorithms is optimized. Fig. 3(a) compares the convergence rate of the three algorithms by observing two principal filter coefficients of recovering the real and imaginary parts of one polarization. The difference between the three algorithms lies in the adapting portion. LMS algorithm adapts based on the error at the current time while the convergence factor for NLMS is variable making the instantaneous output error minimal. The RLS algorithm minimizes a weighted linear least-squares cost function relating to the input signals and adapts based on the total error computed from the beginning. As expected, the RLS algorithm for MIMO has a fast convergence rate while the LMS-based MIMO is the lowest. Fig. 3 (a) and (b) study GMI performance when the remote LO undergoes various SOP rotation rates. To track the fast SOP evolution, the coefficients of the MIMO are updated once every 4096 samples or 1024 samples for this 1.08-Tb/s transmission experiments. The polarization tracking speed of LMS and NLMS based MIMO can reach 314 krad/s for the coefficients updated once every 4096 symbols and 500 krad/s for the coefficients updated once every 1024 symbols without GMI performance degradation. Although the NLMS based MIMO has a faster convergence rate than LMS, the improvement of polarization tracking speed of NLMS is small. By using the RLS-based MIMO for this 1.08-Tb/s C-PDCR, the polarization tracking speed is 1 Mrad/s without GMI performance degradation. Moreover, its recovered GMI performance is better than the other two algorithms since total errors are used for coefficients updating. When 0.3-bits/symbol GMI penalty (corresponding to 1-dB OSNR penalty) is allowed, the polarization tracking speed of RLS-based MIMO can exceed 2 Mrad/s, which manifests that our proposed C-PDCR would be a promising candidate for being deployed in diverse electromagnetic and mechanical environments.

4. Conclusions

We have proposed and experimentally demonstrated a C-PDCR with DSP-based polarization control for the remote LO. The polarization tracking capability for the remote LO is verified by a 1.08-Tb/s transmission experiment and can exceed 2 Mrad/s with a 1-dB OSNR penalty. The proposed C-PDCR could be a good candidate for next-generation 800G/1.6T short-reach optical interconnections.

5. References

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