Polarization-Insensitive Simplified Self-Heterodyne Detection Based on Optical Frequency Comb in MCF Transmission System

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Abstract: We propose a polarization-insensitive space-division multiplexing scheme with self-heterodyne detection by simplified one balanced photodiode receiver based on optical frequency comb. A 17×200-Gb/s 16QAM transmission over 1-km 19-core fiber using low-cost DFB laser is demonstrated. © 2023 The Author(s)

1. Introduction

With the explosively growing of emerging cloud-centric services and applications, data traffic of short-reach optical interconnections becomes increasingly important in modern society. Although the intensity modulation and direct detection (IMDD) scheme has been popularly used in intra-data centers (IDC) due to its cost-effectiveness, it is difficult to deal with large capacity demand of optical interconnects because of poor receiver sensitivity and tolerance ability to channel impairment [1, 2]. Coherent detection has the supreme benefits of high sensitivity, high spectrum efficiency (SE) and good tolerance to channel impairments. However, the conventional intradyne coherent scheme with polarization multiplexing is too complicated and too expensive for short-reach applications. It needs expensive narrow-linewidth lasers and power-hungry digital signal processing (DSP) [3]. While data center applications require those receivers to satisfy strict constraints on cost and power consumption. As a compromise, self-homodyne coherent detection (SHCD) technology has recently been proposed in space-division multiplexing (SDM) systems using multi-core fiber (MCF). A transmitted pilot-tone (PT) originating from the transmitter laser is used as local oscillator (LO) for coherent reception, which avoids the requirement of narrow-linewidth lasers and high-speed carrier-phase recovery DSP in the receiver [4-5]. However, the SHCD still needs to utilize the complex coherent receiver scheme, and require the adaptive polarization controllers (APCs) to manage the polarization of LO [6].

To further simplify the coherent receiver structure, we propose a self-heterodyne detection structure based on optical frequency comb in low-crosstalk MCF with simple balanced photodiode (BPD). The Alamouti polarization-time block coding is adopted to avoid the use of APC [7]. By employing SDM with the pilot-tone and clock-tone transmitted through 2 channels, we experimentally demonstrate a 17×200-Gb/s transmission over 1-km 19-core fiber based on 16 quadrature amplitude modulation (16QAM). The performances in a single channel using both external cavity laser (ECL) and low-cost distributed feedback (DFB) laser are investigated. In this proposed scheme, the frequency offset is fixed, the phase noise compensation and clock recovery can be saved in DSP. The receiver structure is significantly simplified and the polarization insensitivity coherent detection is achieved.

2. Principle of proposed self-heterodyne detection system scheme

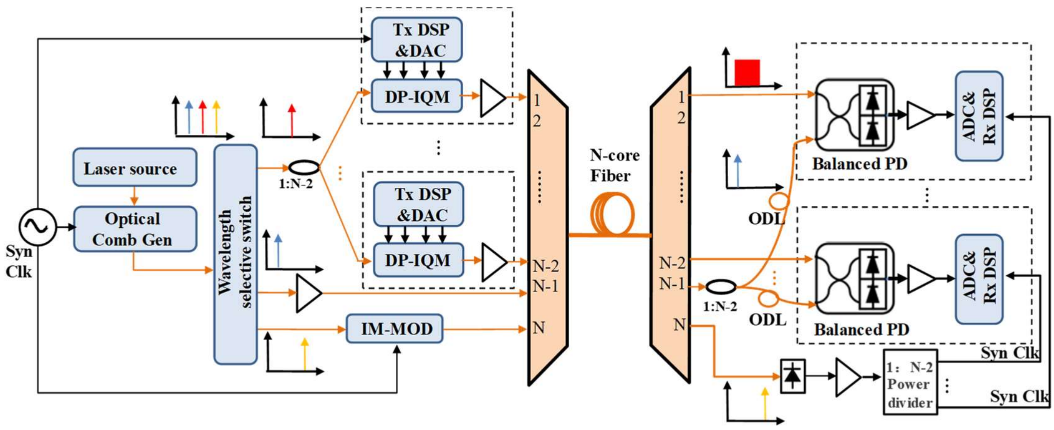

Fig. 1 Scheme of the proposed polarization-insensitivity self-heterodyne detection system.

The proposed polarization-insensitivity SDM scheme based on self-heterodyne detection with N-core low-crosstalk fiber is illustrated in Fig. 1. At the transmitter side, three combs are generated by optical comb generator from one laser source, and then separated to three tones by a wavelength selective switch (WSS). One tone used as signal carrier is spitted into (N-2) paths, and then modulated by the Alamouti-coded high modulated signal with dual-polarization I/Q modulator (DP-IQM). The second pilot tone is used as remote LO to achieve heterodyne detection of the signals. The third clock-loaded tone is used to load reference clock to synchronize the Tx and Rx units. The modulated signals and the other two tones are launched into the N-core fiber through the fan-in device after being amplified. After MCF transmission, the optical signals and two tones are de-multiplexed by a fan-out device. The reference clock is detected from the clock-loaded tone by a photodetector. After amplified and divided by a power divider, the reference clock is sent to the receiver for synchronization. The remote LO is split into (N-2) parts and sent to the simplified BPD together with the signal. The optical delay lines (ODLs) are used to synchronize the optical signal and the LO for phase noise cancellation. After heterodyne detection and analog-to-digital converter (ADC), the signals are Alamouti-decoded and recovered in DSP. The frequency/phase estimation cancellation and polarization independence are obtained by the proposed scheme with this simple single-polarization heterodyne receiver. The scheme can also work symmetrically in bidirectional transmission with the lasers at two sides operating at different wavelengths.

3. Experimental Setup

The experimental setup of the 17×200-Gb/s transmission with polarization-insensitivity self-heterodyne detection is described in Fig. 2. At the transmitter side, we use a RF source of 30-GHz and intensity modulator to generate 3 comb lines. The seed laser is ECL or DFB with linewidths of 10-MHz. A waveshaper flattens the combs and output three ones. The middle comb line with the seed frequency of 192.1488-THz is modulated with 50-Gbaud Alamouti-coded DP-16QAM signal by DP-IQM. The 50-GBaud 16QAM signal with roll-off factor of 0.01 is generated offline and sent by an arbitrary waveform generator (AWG, Keysight M8195A) operating at 64-GSa/s. The left comb line is used as the remote LO. The right comb line is modulated by a Mach Zehnder modulator (MZM) with the 10-MHz clock which is also sent to the RF source and AWG for clock synchronization. The 16QAM modulated signal are divided into 17 channels by a 1x17 splitter after EDFA, and then launched into 19-core fiber by fan-in device together with other two tones using core 8 and core 12. After transmitted over 1-km MCF and de-multiplexed by a fan-out device, a 10-MHz clock is detected by a photodetector from channel 12 and sent to DSO after TIA. The signal and the remote LO from channel 8 are injected into BPD to achieve heterodyne detection. Variable optical attenuators (VOAs) are utilized to emulate the splitter and adjust the received optical power. ODL is inserted in the LO branch to match the propagation delays of signal and LO. The detected electrical signal is captured by a 256-GSa/s digital sampling oscilloscope (DSO, Keysight UXR0594A), and then processed in offline DSP, which contains the functions of down-conversion, resample, frame synchrony, Alamouti equalizer and bit error rate (BER) counter. The optical spectrums of the modulated signal, pilot-tone and clock-tone are shown in the inset (II). The recovered constellation of 16QAM signal at receiver side is shown in the inset (III). The Tx and Rx DSP flows are shown in the inset (I) and (IV).

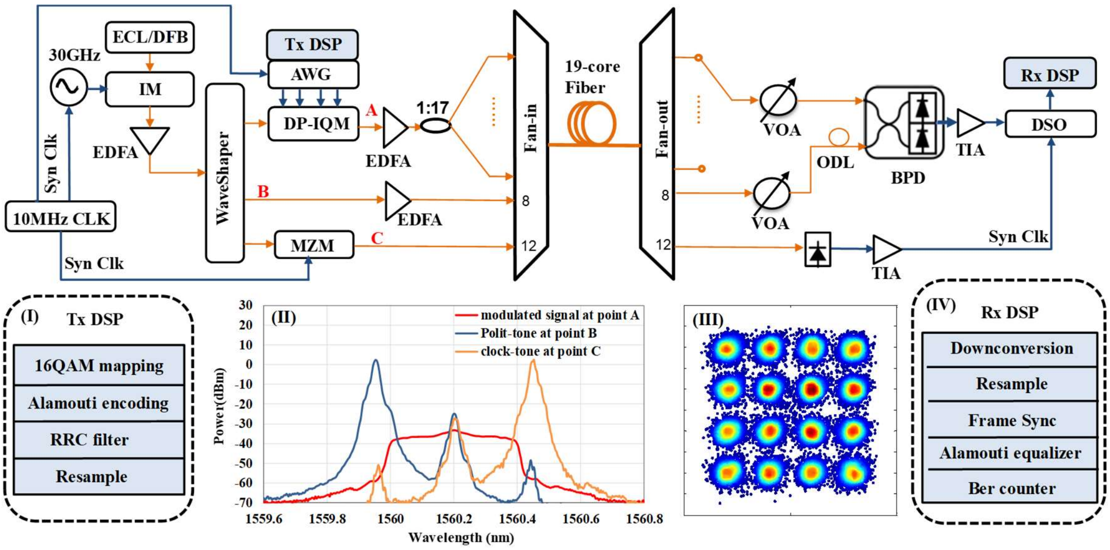

Fig. 2 experimental setup for 17×200-Gb/s transmission with self-heterodyne detection. (I) Tx DSP flow; (II) Optical spectrums of the modulated signal, pilot tone and clock-tone; (III) recovered constellation of 16QAM signal; (IV) Rx DSP flow.

4. Experimental Results

First, we investigate the BER performances of 50-Gbaud 16QAM signal based on the proposed system in optical back-to-back (BTB) case with different lasers. The BER versus the received optical power (ROP) of LO is shown in Fig. 3(a). For ECL and DFB cases, the LO power need to be above -9 dBm and -7 dBm separately. LO over 2 dBm will result in the performance deterioration due to the introduced nonlinear distortions. Then we keep the received LO power at 2 dBm and measure the BER performance by varying the ROP of signal. As shown in Fig. 3(b), the performance of the system using larger linewidth DFB do not have distinguished penalty compared to that of system using ECL. The minimum ROP is about -14 dBm to reach the 1.5×10^{-2} HD-FEC threshold when using DFB laser.

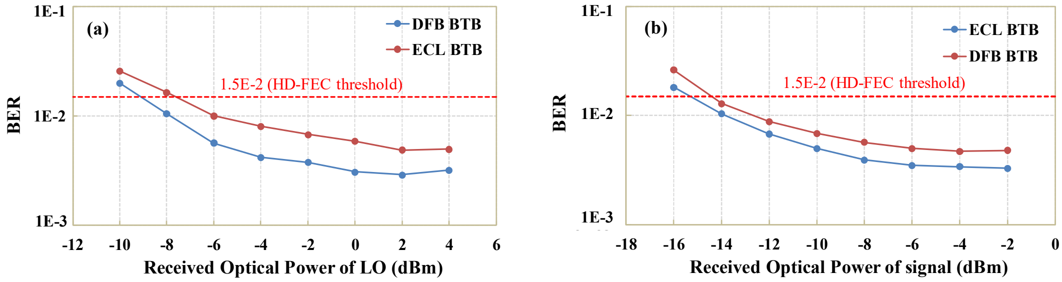

Fig. 3 BTB results for (a) BER versus received power of LO; (b) BER versus received power of signal with LO at 2 dBm.

Next, we study the performance of 1-km transmission over low-crosstalk 19-core fiber. Due to the loss of 1×17 splitter and other loss in the link, the input power of the remote LO in core 8 at transmitter side is set to 17 dBm to get the LO power of 2 dBm at receiver side. The BERs versus the received ROP for several spatial channels (core 6, core 11, and core 16) under ECL and DFB are depicted in Fig. 4(a). The results show that there is about 1 dB performance degradation compared to the BTB case and the results of different channels are similar. The self-heterodyne detection architecture mitigate the additional phase noise at the receiver, leading to small performance gap between ECL and DFB laser transmitters. We finally measure the BER performances of all the 17 cores with launched power at 4 dBm in each core when DFB is used as laser source. As shown in Fig. 4(b), the BERs on all cores are below1.5×10^{-2} and the results indicate that 17×200-Gb/s SDM signal can be successfully transmitted by employing the proposed scheme.

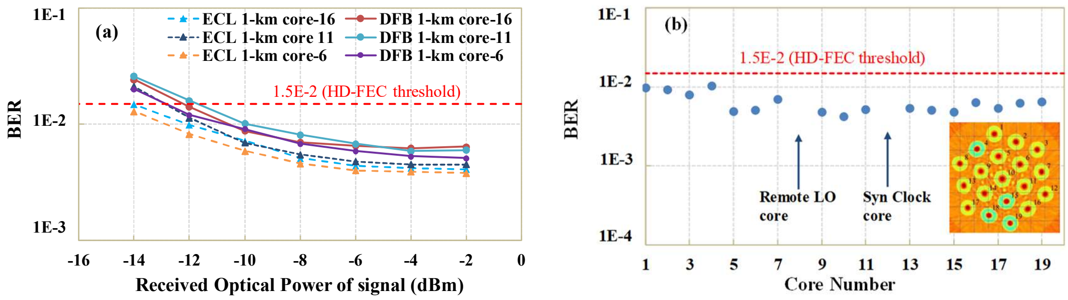

Fig. 4 (a) 1-km MCF BER vs ROP results for several channels under ECL and DFB cases, (b) BERs of all channels under DFB case.

5. Conclusion

A polarization-insensitive SDM scheme based on self-heterodyne detection by simplified one BPD receiver using low-crosstalk MCF is proposed. The frequency offset estimation, phase recovery and clock recovery are saved in DSP based on this scheme. The polarization independency is achieved by employing Alamouti-coding. An experiment of 17×200-Gb/s 16QAM transmission over 1-km 19-core fiber is realized by the proposed scheme using DFB laser with only small performance penalty compared to ECL.

6. Acknowledgements

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7. References

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