Demonstration of 50-Gb/s/λ PAM-4 PON with Single-PD using Polarization-Insensitive and SSBI Suppressed Heterodyne Coherent Detection

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Abstract: A polarization-insensitive heterodyne coherent detection with single-PD for 50-Gb/s/λ PAM-4 PON is experimentally demonstrated. Over 40- and 39-dBm power budgets are achieved after 20-/50-km SSMF transmission under 7% FEC threshold, respectively. © 2020 The Author(s)
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1. Introduction

With the exponentially increasing bandwidth demand due to high-definition video, virtual/augment reality and cloud network applications, high speed passive optical networks (PONs) are being developed [1]. The intensity modulation and direct detection solution suffers from the limitations including poor receiver sensitivity, power fading due to chromatic dispersion at high symbol rates and long transmission distances with PON moving towards 50-Gb/s/λ and beyond. On the other hand, coherent detection is an effective way to increase the receiver sensitivity and enable chromatic dispersion post-compensation [2]. However, it comes at a greater financial cost, due to the high optical complexity of complicated I/Q modulators as well as integrated coherent receiver.

To make coherent detection technology viable for PON, several simplified coherent structures have been proposed [3-7]. Among these schemes, Alamouti coding is an effective way to realize polarization independent coherent detection, which makes the hardware complexity of polarization diversity coherent receiver to be reduced in half [4]. The real-valued Alamouti-coding scheme for PAM-4 signals can also obtain the polarization independence without using any I/Q modulators [5]. To further simplify the coherent receiver, heterodyne coherent detection with single- photodiode (PD) was also proposed in PON [6, 7]. However, either guard band [6] or Kramers-Kronig (KK) based signal-to-signal beat interference (SSBI) cancellation [7] was employed, leading to the reduction of bandwidth efficiency or increase of digital signal processing (DSP) complexity. Recently, a simplified single-photodiode per polarization heterodyne receiver was proposed for 400Gb/s transmission system [8], which is able to directly suppress SSBI without guard band or SSBI cancellation in the digital domain.

In this paper, the polarization-insensitive and SSBI suppressed heterodyne coherent detection with single-PD for 50-Gb/s/λ PAM-4 PON is experimentally demonstrated for the first time. For the optical line terminal (OLT), 25-Gbaud PAM-4 amplitude modulated is performed without using any I/Q modulator. The real-valued Alamouti coding scheme is employed to encode the PAM-4 signals to provide polarization independence at the optical network unit (ONU). For ONU, heterodyne coherent detection with single-PD is applied. Noting that, a powerful local oscillator (LO) at ONU enables SSBI to be suppressed via the detection process, instead of neither SSBI cancellation scheme in the digital domain nor guard band between LO and signals. Receiver sensitivity of -32dBm is achieved at BER of 3.8×10^{-3}, and about 40 and 39-dBm power budget is enabled after 20 /50-km standard single mode fiber (SSMF), respectively.

2. Experimental Setup

Figure 1 shows the experimental setup of our demonstrated 50-Gb/s/ PAM-4 PON using polarization-insensitive heterodyne coherent detection with single-PD in the C-band. At the transmitter, a pseudo random binary sequence (PRBS) with length of $2^{17}-1$ is first mapped to PAM-4 format, and then processed by the real-valued Alamouti encoding scheme [5]. The synchronization header and the digital pilot used for frequency offset estimation are inserted prior to the payload, constituting a complete frame. Then, the frames for X- and Y- polarization are up-sampled to 2 samples per symbol for Nyquist pulse-shaping with roll-off factor of 0.1. After that, the output sequence is down-sampled to 1.28 samples per symbol to achieve higher bit rate and the arbitrary waveform generator (AWG) is operating at 64-GSa/s. Thus, the symbol rate is 25-GBaud. Considering the 0.1 roll-off factor,

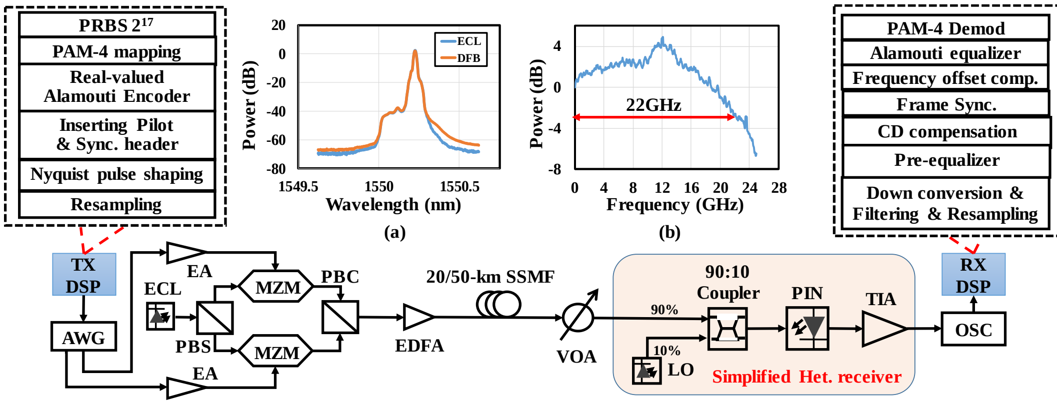

Fig. 1. Experimental setup of 50-Gb/s/λ PAM-4 PON in the C-band using polarization-insensitive heterodyne coherent detection with single-PD: (a) the optical spectra of combined signal with ECL or DFB laser as LO after the coupler (b) transfer function of the O/E front-end response. LO: local oscillator. PBS: polarization beam splitter. PBC: polarization beam combiner. OSC: oscilloscope. VOA: variable optical attenuator. EA: electrical amplifier. EDFA: erbium doped fiber amplifier. Sync.: synchronization. Comp.: compensation. Het.: heterodyne.

the bandwidth of the signal is about 13.5-GHz. The two output electrical signals from AWG are amplified by two 28-GHz electrical amplifiers before driving the dual-polarization Mach-Zehnder modulator (MZM). A continuous-wave light generated by the external cavity laser (ECL) at 1550.0-nm (100-kHz linewidth) is split into two polarizations using a polarization beam splitter, and then used as the optical inputs of the two MZMs. The modulated optical signals are then combined by a polarization beam combiner, and amplified by an EDFA. After 20/50-km SSMF transmission, the received optical signal is passing through a variable optical attenuator to adjust the received optical power (ROP) before sending into the simplified heterodyne coherent receiver. An ECL with 100-kHz linewidth is used as the LO with power of 15-dBm, and a low cost DFB laser with about 5-MHz linewidth is alternatively employed as LO for performance comparison. The LO was frequency offset from the signal's optical carrier by the bandwidth of the signal that equals to 13.5GHz, which means that no guard band is remained for SSBI. Then, the signal and LO are mixed in a 90:10 optical coupler, and detected by a PIN photodiode with 22-GHz optical bandwidth. Considering the insertion loss, the power of LO into PD is constantly around 4.5dBm. Fig. 1(a) gives the optical spectrum of combined signal with ECL or DFB laser as LO after the coupler, respectively. Finally, the output electrical signals from TIA are fed into a LeCroy real-time oscilloscope, acquired at sampling rate of 160-GSa/s, and processed offline DSP. In the receiver DSP, the signals are firstly down-converted with low-pass filtering and then re-sampled to two samples per symbol. Then, a finite impulse response pre-equalization filter is applied to compensate the front-end response, whose transfer function is shown in Fig. 1(b). Chromatic dispersion compensation is also enabled before frame synchronization. After that, the pilot can be extracted and utilized to estimate the carrier frequency offset. Following this stage, joint channel equalization and phase estimation is performed using an Alamouti equalizer [4]. Finally, BER can be calculated after PAM-4 demodulation.

3. Results and discussions

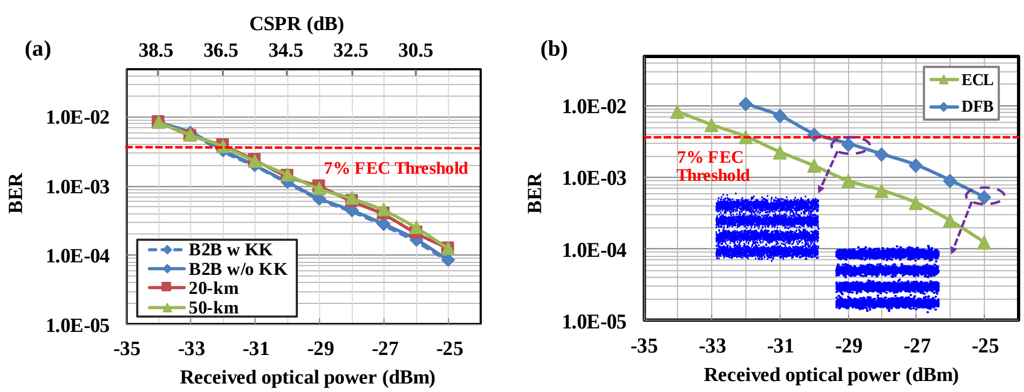

Fig. 2. (a) BER performance versus ROP for B2B, 20- and 50-km SSMF transmission, respectively; (b) BER performance versus ROP using ECL and DFB laser as LO, respectively.

We firstly measure the BER performance versus ROP for back-to-back (B2B) with and without KK reception for SSBI cancellation, respectively. Here, KK reception is used as the first step in the receiver DSP flow, prior to down-conversion. As shown in Fig. 2(a), we can obtain almost identical sensitivity with and without KK reception, when ROP is smaller than -25-dBm. The corresponding carrier-to-signal power ratio (CSPR) (= 4.5dBm − ROP) is also listed in the upper horizontal axis. It indicates that a strong LO providing a relatively high CSPR is able to suppress SSBI, removing the need for KK DSP. Considering the required ROP is -32dBm (corresponding to CSPR of 36.5-dB) for FEC threshold of 3.8×10^{-3} (corresponding to 7% overhead), KK is not used in the following experiments. The BER versus ROP for 20- and 50-km fiber transmission cases are also evaluated. In this experiment, we keep the launch power at 6-dBm. After 20/50-km fiber transmission, there is no obvious penalty at the FEC threshold, as shown in Fig. 2(a). We also compare the receiver sensitivity using ECL and DFB laser as LO after 50-km fiber transmission, respectively. As shown in Fig. 2(b), around 2.5-dB penalty is caused by larger linewidth of DFB laser. The scatter diagrams at ROP of -29-dBm and -25dBm using DFB laser are also inserted. In the following experiment, we employ ECL as LO to obtain better performance.

Then, we evaluate the performance with different launch power, as shown in Fig. 3(a). Due to the fiber nonlinearity, the BER performance at ROP of -31dBm after 20- and 50-km fiber transmission is getting worse when the launch power increases over 7-dBm. The total link power budget as a function of launch power is also shown in Fig. 3(a). It is shown that the maximum power budgets of 40 and 39 dB are achieved after 20-and 50-km fiber, respectively. Finally, we evaluate the BER under various frequency spacing between signal and LO at ROP of -30dBm at B2B. There is less than 1-dB penalty within 3.5-GHz frequency drift, as shown in Fig. 3(b).

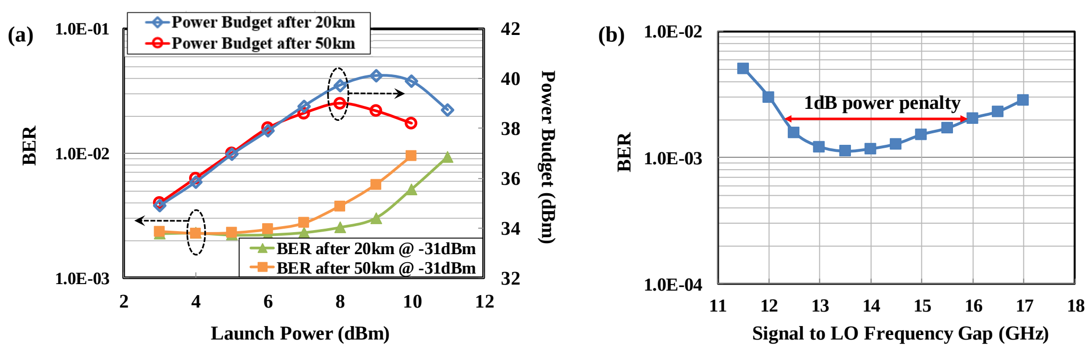

Fig. 3. (a) The BER and power budget versus launch power after 20 and 50-km fiber transmission, respectively; (b) BER under various frequency spacing between signal and LO at ROP of -30dBm.

4. Conclusion

We experimentally demonstrated a simplified polarization-insensitive heterodyne coherent detection for 50-Gb/s/λ PAM-4 PON. Only two MZMs were required for the transmitter, and single-PD was required for the receiver. Besides this, SSBI can be suppressed without guard band or SSBI cancellation in the digital domain. About 40- and 39-dBm power budget was enabled after 20-/50-km SSMF transmission.

5. Acknowledgements

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