Experimental Demonstration of 100/200-Gb/s/λ PON Downstream Transmission Using Simplified Coherent Receivers

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Abstract: We demonstrate 100- and 200-Gb/s/λ line-rate PON downstream transmission considering Alamouti-coded 16QAM signal with a single-polarization heterodyne receiver. The power budget is experimentally evaluated for both single-ended and balanced detection considering 25 km reach. © 2022 The Author(s)

1. Introduction

To meet the increasing bandwidth demand of access networks, the IEEE has recently standardized a 25 Gb/s line-rate PON while the ITU-T consider a 50 Gb/s line-rate [1]. As a next step, the research for the future generations of PON has already started considering a data rate of 100 Gb/s and 200 Gb/s [2,3]. For such a high-rate system, currently used intensity modulation and direct detection technique will not be feasible to meet the required loss budget of the deployed optical distribution networks (ODNs). Due to high receiver sensitivity and the use of digital signal processing (DSP) for compensation of transmission impairments, coherent technology is considered as a rational alternative for next-generation PON at 100 Gb/s+ [4].

However, the complexity/cost of conventional dual-polarization coherent receiver used in the long-haul system is not suitable for access application. Therefore, reduced-complexity coherent receiver design for PON application has recently attracted significant attention [5,6]. The use of single-polarization and heterodyne detection largely simplify the coherent receiver requiring only a 3-dB coupler and a single balanced photodiode [7]. The polarization insensitive operation can be achieved at the transmitter side using polarization-time coding such as Alamouti-coding. Such an approach comes with the expense of a larger bandwidth requirement. However, considering the cost of the packaging is dominated by the number of ports and not as much by the bandwidth, the packaging cost for a single-polarization heterodyne receiver will be much lower than the conventional intradyne receiver as the number of interfaces is largely minimized.

In this paper, first, we have experimentally demonstrated, 100- and 200-Gb/s downstream transmission with 16-QAM modulation format over a 25 km of standard single-mode fiber (SMF) utilizing the simple single-polarization heterodyne receiver employing a balanced photodiode with 10 dBm LO power and achieved a power budget of 37.7 dBm and 32.8 dBm, respectively. To the best of our knowledge, this is the first demonstration of 200 Gb/s/λ downstream transmission with such a simplified receiver. In addition, we investigate the performance of a further simplified coherent receiver by using a single-ended photodiode instead of a balanced photodiode. Such front-end is as simple as conventional direct detection receiver. Though the performance of single-ended detection is inherently degraded compared to the balanced detection, we still achieve a power budget of 32 dB and 26.6 dB for a data rate of 100 Gb/s and 200 Gb/s, respectively. Increasing the LO power to 15 dBm, the power budget is raised to 27.9 dB for 200Gb/s data rate with single-ended detection.

2. Experimental Setup

The experimental setup used to assess the performance of the proposed 100/200-Gb/s PON downstream transceiver is shown in Fig. 1. At the transmitter, first, a 25 Gbaud or 50 Gbaud Alamouti-coded 16-QAM signal waveforms are generated offline for a data rate of 100 Gb/s or 200 Gb/s, respectively. The signals are then pulse-shaped with a root raised cosine (RRC) filter having a roll-off factor of 0.01. They are then loaded to an 8 bit, four-channel, 100 GSa/s digital-to-analog converter (DAC) to generate the driving signals. The optical signal is generated using a commercial optical multi-format transmitter with 6-dB bandwidth of 40 GHz comprised of a tunable laser operating at C-band, InP-based dual-polarization IQ modulator and four RF driver amplifiers. An erbium-doped fiber amplifier (EDFA) with a noise figure of 4.5 dB is used to set the launch power into the fiber, which is varied to investigate the receiver sensitivity performance and find the optimum launch power considering both linear and nonlinear fiber transmission impairments.

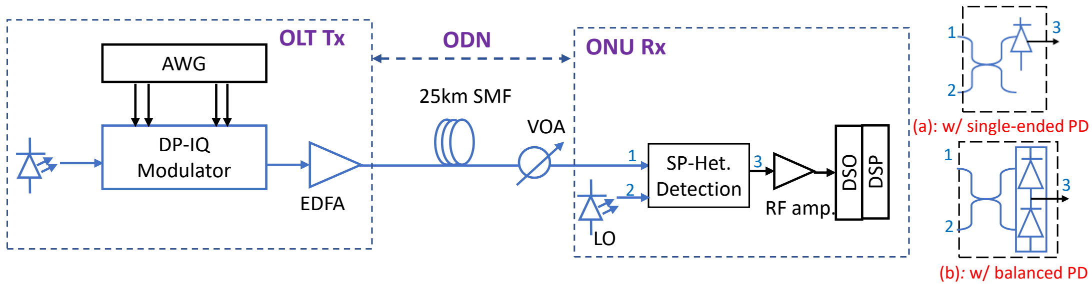

Fig.1: Experimental setup to evaluate the performance of 100/200 Gb/s downstream transmission. Inset (a) is for single-ended detection and (b) is for the balanced detection case.

The optical signal is then transmitted through 25 km of standard SMF having an attenuation coefficient of 0.22 dB/km. For receiver sensitivity measurements, the signal power is varied using a variable optical attenuator (VOA), which also emulates the splitter loss in a typical ODN.

The simplified coherent receiver front-end is composed of a 3-dB wideband 2x2 coupler and a 70 GHz balanced photodiode. For single-ended detection case, we use only one input port of the balanced photodiode. For the LO, an external cavity laser (ECL) is used which is tuned at an emission frequency 13.5 GHz (for 25Gbaud signal) or 26 GHz (for 50Gbaud signal) above the transmitting laser frequency and power is set to 10dBm unless specifically mentioned. Following the photodetection, the received electrical signal is amplified using a 60 GHz broadband linear RF amplifier and digitized using a digital sampling oscilloscope (DSO) with a single 10-bit analog-to-digital converter (ADC) operating at a sampling rate of 256 GSa/s and a bandwidth of 50 GHz. Therefore, the receiver bandwidth is mainly limited by the bandwidth of DSO which is 50GHz.

In the offline receiver DSP, first, the IF is estimated, and the signal is downconverted to baseband. Then, a frequency domain fixed chromatic dispersion filter is used in the case of fiber transmission. After the frame synchronization, the signal is resampled at two samples per symbol. Then it is processed with least-mean-square (LMS)-based Alamouti-coded DSP as explained in [8] to perform adaptive equalization and carrier phase recovery. The symbols are then decoded and the bit-error-rate (BER) is measured by the direct error counting method.

3. Results and Discussion

To determine the optimum launch power considering both linear and nonlinear fiber impairments, we vary the launch power into the fiber and evaluate the power budget at the BER FEC limit of 10^{-2}. Such measurement results for the 100 Gb/s data rate are shown in Fig.2(a). The optimum launch power of 11 dBm is obtained. The maximum power budget of 37.7 dB and 32 dB is achieved for balanced detection and single-ended detection, respectively. Though the power budget is reduced by 5.7 dB for single-ended detection, still we can achieve beyond the N1 class (*i.e.* >29 dB) loss budget of ITU-T standards.

We also measure the BER performance as a function of received power for back-to-back, 25 km transmission with 0 dBm launch power (linear region) and 11 dBm launch power (optimum launch power). It is found that when the launch power is low (0 dBm), there is no significant sensitivity penalty as the linear impairments are compensated in the DSP. However, for the higher launch power of 11 dBm, the sensitivity is degraded due to fiber

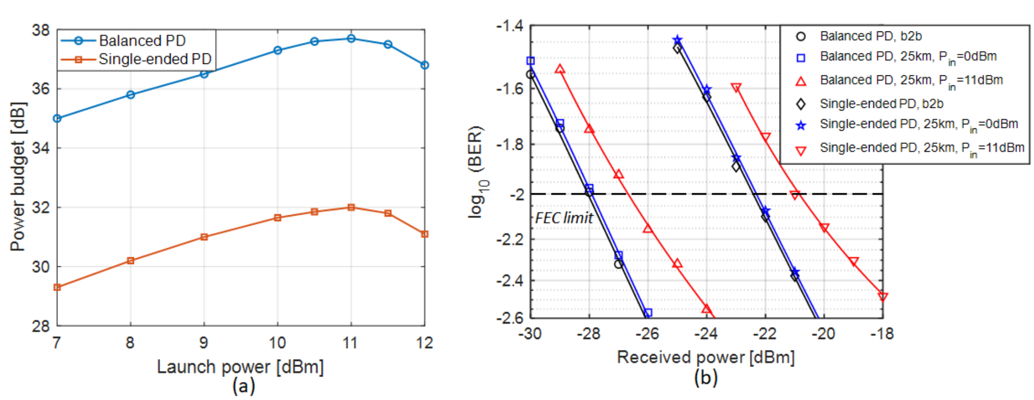

Fig.2: Experimental results for 100Gb/s transmission, (a): power budget as a function of launch power, (b): BER vs received power for different launch power. The LO power is 10 dBm unless specifically mentioned.

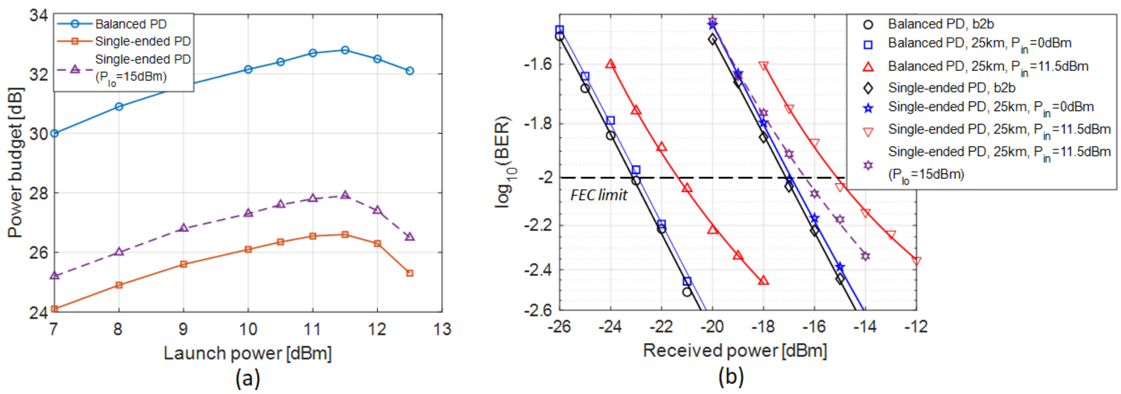

Fig.3: Experimental results for 200Gb/s transmission, (a): power budget vs launch power, (b): BER vs received power for different launch power. The LO power is 10 dBm unless specifically mentioned.

nonlinearity, nevertheless, we can still achieve the maximum power budget at such launch power. There is a back-to-back sensitivity degradation of about 5.5 dB between balanced and single-ended detection. Such degradation is due to not using one coupler output port as well as common-mode noise such as LO-RIN is not canceled out in the case of single-ended detection.

The power budget against launch power for 200 Gb/s is depicted in Fig.3(a). The optimum launch power is 11.5 dBm and we can achieve a maximum power budget of 32.8 dB and 26.6 dB for balanced and single-ended detection, respectively. Therefore, there is a 6.2 dB of power budget degradation in the case of single-ended detection.

To investigate the performance improvement for single-ended detection, we increase the LO power from 10 dBm to 15 dBm, and the power budget is improved to 27.9 dB as shown by the dotted line in Fig. 3(a). This is due to less impact of thermal noise at higher LO power.

We also evaluate the receiver sensitivity for the back-to-back and 25 km transmission cases for different launch powers as shown in Fig. 3(b). Similar to 100 Gb/s results, there is no considerable penalty between back-to-back and 25 km transmission when launch power is low. However, at optimum launch power of 11.5 dBm, the sensitivity degrades due to fiber nonlinearity, still, the maxim power budget is attained at such launch power. The back-to-back sensitivity degradation for single-ended detection is measured around 6 dB.

4. Conclusion

We have experimentally demonstrated 100- and 200-Gb/s/λ PON downstream transmission over 25 km of standard SMF in C-band using a simplified coherent receiver comprised of a 3-dB optical coupler and a single balanced photodiode. The results are then compared with a further simplified receiver employing a single-ended photodiode instead of balanced photodiodes. For 100 Gb/s data rate, a power budget of 32 dB and 37.7 dB is achieved for single-ended and balanced detection, respectively considering 10 dBm LO power. On the other hand, for 200 Gb/s downstream, a power budget of 32.8 dB is obtained for balanced detection. The power budget is degraded for single-ended detection; however, we can still achieve 26.6 dB and 27.9 dB for a LO power of 10 dBm and 15 dBm, respectively.

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