200-Gb/s/λ Coherent TDM-PON with Wide Dynamic Range of >30-dB based on Local Oscillator Power Adjustment

Guoqiang Li[1], Sizhe Xing[1], Zhongya Li[1], Junwen Zhang[1, 2*], Nan Chi[1, 2]
[1]MoE Lab, Fudan University, Shanghai 200433, China, [2]Peng Cheng Lab, Shenzhen 518055, China
E-mail address: junwenzhang@fudan.edu.cn

Abstract: We experimentally demonstrate the 200-Gb/s/λ PDM-16QAM coherent TDM-PON data transmission with wide dynamic-range based on the local-oscillator power adjustment for continuous and burst-mode signals, achieving >30-dB dynamic-range and 37-dB power budget over 50-km SSMF transmission. © 2022 The Author(s)

1. Introduction

Driven by the development of fifth and sixth generation (5G/6G) networks and multimedia services such as high-definition 8K/16K video stream, three-dimensional display and AR/VR applications, larger bandwidths are required in optical access networks [1]. Recently, the standardization of 50 Gb/s per wavelength high-speed passive optical network (PON) is close to be completed by ITU-T [2]. To support the continuously growing bandwidth demand toward 2030, it is envisioned that 100 Gb/s or beyond PON will be required [3]. Compared with intensity modulation and direct detection (IM/DD) system, coherent PON is a promising solution for next generation 100G and beyond high-speed PON thanks to its better sensitivity and larger power budget [4]. Single-wavelength 100G TDM PON was demonstrated with more than 36-dB power budget in [5]. A 200 Gb/s/λ coherent PON system was also demonstrated recently in [3], which heralds the rising interests for beyond 100 Gb/s PON.

Coherent detection has the advantage of superior receiver sensitivity, and theoretically can provide much wide dynamic range [4, 5]. However, due to the limited dynamic range of the analog-to-digital converters (ADCs), the dynamic range is limited. Nonlinear impairments happen due to the clipping of high-power signal under too small ADC scales, while the quantization noise is high for low-power signals with too-large ADC scales. Especially in the TDM-PON upstream, the coming burst signals naturally have widely varying signal powers and it is unrealistic to detect all these signals without receiver settling process. Previous works have been done to handle the various power levels and enlarge dynamic range of the receivers by using burst-mode optical or electrical pre-amplification schemes to level the burst signals before input to the ADCs [6, 7]. Instead of adjusting the power level of the burst signals, optical pre-amplification based on a power-controlled local oscillator (LO) was also demonstrated in OFDM 16QAM coherent PON system to meet the linearity requirement and satisfy the dynamic range [8].

In this paper, we experimentally demonstrate the 200-Gb/s/λ PDM-16QAM coherent TDM-PON data transmission with wide dynamic range based on the LO power adjustment for continuous and burst-mode signals. The system performance is also studied under different implementation conditions. Finally, we achieve an extended dynamic range to more than 30dB, with 37.5-dB and 37-dB power budget for 200 Gb/s/λ coherent TDM-PON continuous and burst-mode signals after 50-km SSMF, respectively.

2. Principles and Architecture

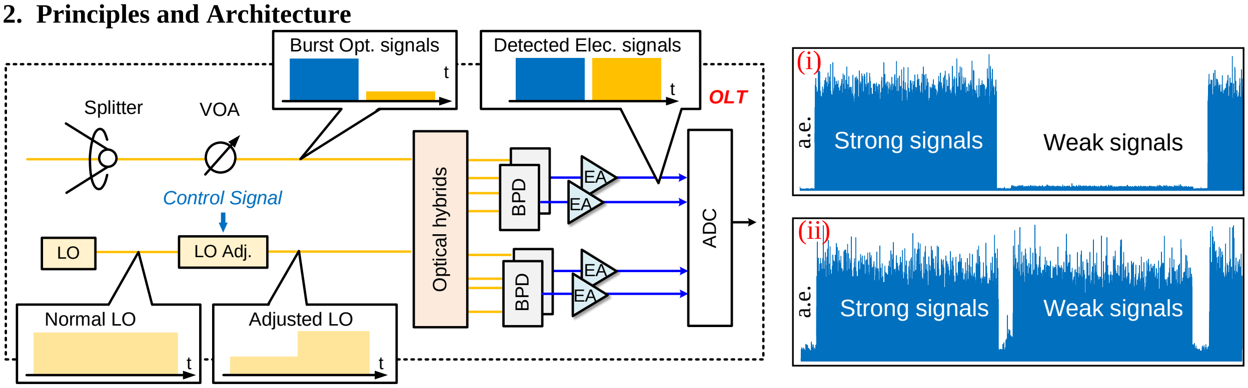

Fig. 1 (a) The configuration of burst-mode coherent receiver based on LO power adjustment. (b) Burst signals (A) before and (B) after detection with power-adjusted LO.

In coherent PON, the power differences between consecutive frames of the upstream burst signals are significant. Due to the insufficient linear response region of the TIA, the input dynamic range of the coherent receiver will be severely limited [7]. Fig. 1 shows the configuration of the burst-mode coherent receiver based on LO power adjustment. The LO is first intensity modulated by a low-frequency multi-level control signal before being inputted to the 90° optical hybrid. The frequency of the control signal is determined by the arrival time and frame length of each burst. Therefore, the power adjustment is implemented for each burst. The signal level corresponding to each burst depends on the optical power of the burst signal. For example, the signal level should be pulled down when received the strong burst signals. Then the power of the detected signals from BPDs can maintain constant to satisfy the input dynamic range of the TIAs. The insets show the burst signals before and after detection with power-adjusted LO. The strong and weak signals will tend to comparable power level to enlarge the dynamic range of the coherent receiver.

3. Experimental Setup and Results

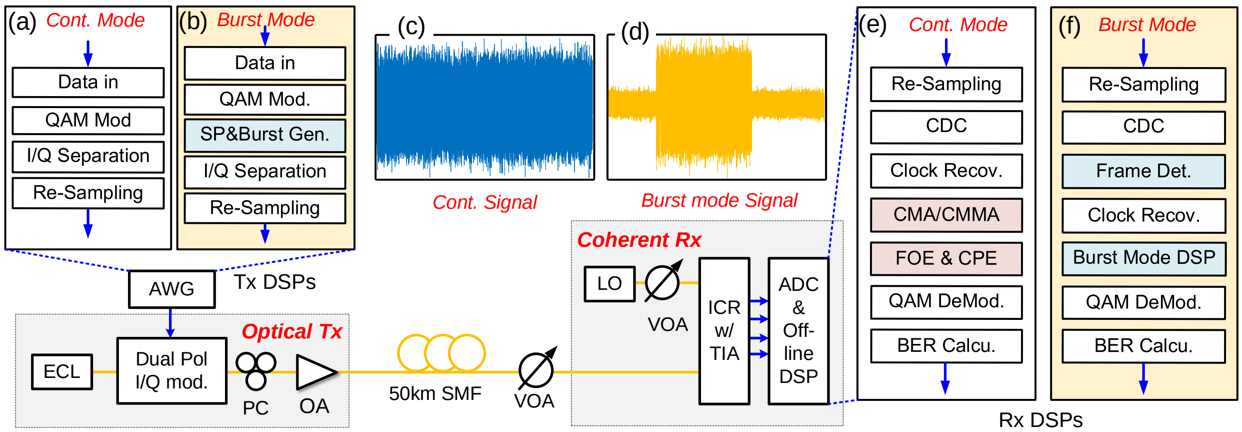

Fig. 2 (a) Experimental setup for 200 Gb/s/λ coherent PON; (b) and (d) are the Tx and Rx DSP for continuous signal; (e) and (g) are the Tx and Rx DSP for burst-mode signal; (c) and (f) are the traced continuous and burst-mode signals.

Fig. 2 shows the experimental setup of the 200 Gb/s/λ coherent TDM-PON. Two external cavity lasers (ECLs, with the same wavelength of 1551.9nm) are used as signal light source and LO for homodyne detection. The 200 Gb/s/λ PDM-16QAM signal is generated by a 120 GSa/s AWG and then modulated by a dual polarization I/Q modulator. The optical signal is boosted by an EDFA before launched into a 50-km SSMF. The power of the EDFA output signal is 7.5 dBm. At the receiver side, a VOA is used for received optical power (ROP) adjustment. The optical signal is detected by an integrated coherent receiver (ICR). The gain of the TIAs in ICR can be adjusted by setting the control voltage in manual gain control (MGC) mode. Here for simplicity, the LO power adjustment is realized by manually adjusting the VOA. The detected signal is captured by an 80 GSa/s DSO for offline DSP. Fig. 2(a) and (e) show the DSP of continuous signal generation on Tx-side and signal recovery on Rx-side to study the performance of the TDM-PON downstream. For signal generation, the origin data is first mapped into 16-QAM signal. After 4 times up-sampling and I/Q separation, the signal is sent to AWG. For receiver-side DSP, clock recovery based on fast square-timing-recovery algorithm is performed after chromatic dispersion compensation (CDC). The signal is then recovered by blind adaptive equalization based on constant modulus algorithm (CMA). After frequency offset/carrier phase recovery (FOE & CPE), the signal is sent to QAM demodulation and BER calculation. Fig. 2(b) and (f) show the DSP to emulate and study the performance of the TDM-PON upstream. Sync patterns (SP) and a sequence of zero are added to generate burst signal at the Tx side. The Rx-side DSP is similar to that in [5]. The burst frame is first detected and synchronized for further burst-mode DSP. Fig. 2(c) and (d) show the traced continuous and burst-mode signals.

We first test the system performance under different implementation conditions. Fig. 3(a) shows the average BER of x- and y- polarization versus ADC sampling scale. The high-power input signal is clipped when the ADC is at a small sampling scale. The induced nonlinearity degrades the BER performance. Lower quantization accuracy will also influence the system performance when setting the ADC at a large sampling scale. Fixed the ADC sampling scale at 0.05 V/div, we test the system performance under different TIA gain control voltage in MGC mode, as showed in Fig. 3(b). A large control voltage means the high TIA gain. The signal-to-noise ratio (SNR) of the output signal at low TIA gain is relatively smaller than that at high TIA gain. However, the over-amplified signal will be affected by the nonlinearity due to the limited ADC sampling scale. The best control voltage is 1.5V at the ROP of -21 dBm. Fig. 3(c) shows the BER performance versus different adjusted LO optical power. The most suitable LO optical power is 9 dBm. The increasement of LO optical power raises the amplitude of the detected signal, and the nonlinearity is introduced. Reducing the LO optical power brings a decrease in the signal SNR.

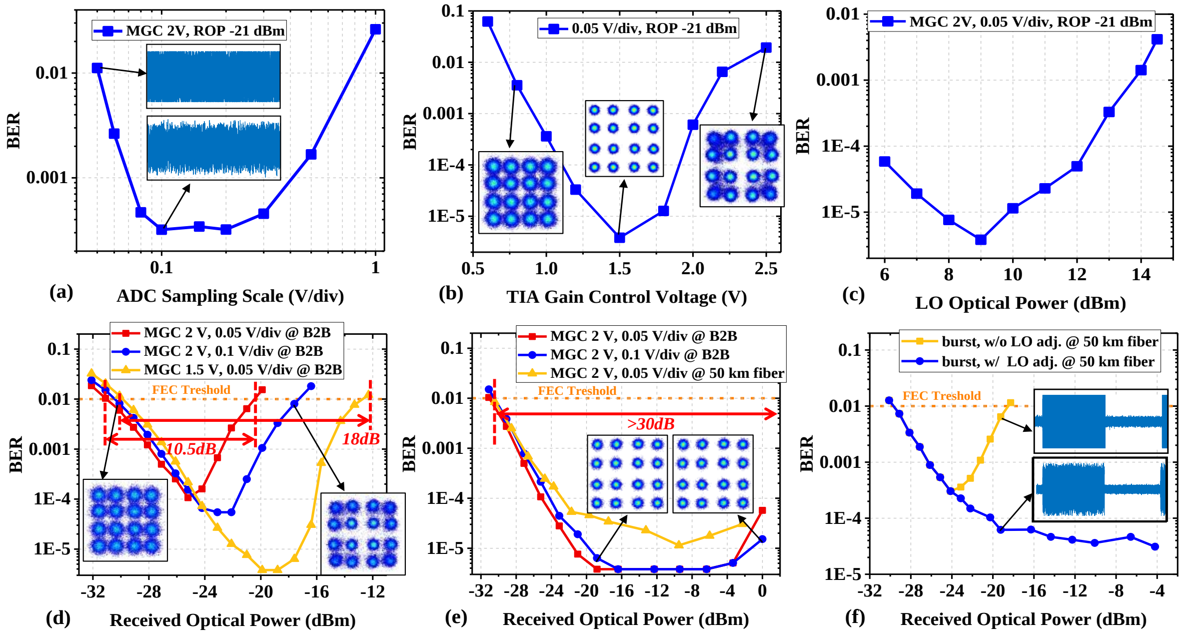

Fig. 3 The results of (a) BER versus ADC sampling scale; (b) BER versus TIA gain control voltage; (c) BER versus LO optical power; The BER performance versus the received optical power: (d) continuous signal without LO power adjustment; (e) continuous signal with LO adjustment; (f) burst signal after 50-km fiber transmission.

To verify the feasibility of the LO power adjustment, we initially test the performance with continuous-mode transmitted signals. Fig. 3(d) and (e) show the calculated BER versus ROP under several cases. Without LO power adjustment, the best sensitivity of -30 dBm in back-to-back (B2B) transmission is obtained at the control voltage of 2V and ADC sampling scale of 0.05 V/div. Under a BER threshold of 1×10^{-2}, a total power budget of 37.5 dB is achieved for continuous transmission, considering 7.5-dBm launch power and -30-dB Rx sensitivity. A smaller TIA gain and larger ADC sampling scale will reduce the system sensitivity. However, the dynamic range under this configuration is limited due to the induced nonlinearity. Enlarge the ADC sampling scale or reduce the TIA gain to avoid signal clipping can expend the dynamic range. A dynamic range of 18 dB is achieved at the control voltage of 1.5V and ADC sampling scale of 0.05 V/div. With LO power adjustment, the dynamic range of the system can be extended to more than 30 dB without degrading the sensitivity, as shown in Fig. 3(e). Acceptable penalty is introduced after 50-km fiber transmission. We only test the system performance at the higher ROP of 0 dBm to protest the ICR. The insets are the corresponding constellations under different ROP without and with LO power adjustment. The result of burst-mode signals after 50-km fiber transmission is shown in Fig. 3(f). Here the gain control voltage is fixed at 2V and the ADC sampling scale is 0.05 V/div. We test the BER performance of the burst strong signals. Similarly with the continuous signal transmission, the dynamic range of the system is limited to 11 dB without LO power adjustment. LO power adjustment enlarges the dynamic range to more than 30 dB. A total power budget of 37-dB is achieved for burst-mode transmission, considering 7.5-dBm launch power and -29.5-dB Rx sensitivity at the BER threshold of 1×10^{-2}. The insets show the traced signal at the ROP of -19.3 dBm. The clipping of the high-power signal results in strong nonlinearity. And LO power adjustment can avoid this situation by reducing the signal amplitude.

4. Conclusions

The 200-Gb/s/λ PDM-16QAM coherent TDM-PON data transmission with wide dynamic range is experimentally demonstrated based on the local oscillator power adjustment for continuous and burst-mode signals. We also study the system performance under different implementation conditions. Finally, an extended dynamic range to more than 30dB is achieved based on the proposed method, with 37.5-dB and 37-dB power budget for 200 Gb/s/λ coherent TDM-PON continuous and burst-mode signals after 50-km SSMF, respectively.

This work was partly support by the NSFC project (No.61925104, No.62031011, No. 62171137) Shanghai NSF project (No. 21ZR1408700) and The Major Key Project of PCL (PCL2021A14).

References

[1] Z. Zhang, et al., IEEE Commun. Mag. 57.4, 144-150 (2019).
[2] J, Wey, J. Light. Technol., 38.1, 31-42(2020).
[3] J. Zhang, et al., J. Opt. Comm. Netw., 12.1, A1-A8(2020).
[4] J. Zhang, et al., in CLEO-PR 2020, paper C5F-1.
[5] J. Zhang, et al., J. Opt. Comm. Netw., 13.2, A135-A143(2020).
[6] R. Koma, et al., J. Light. Technol., 35.8, 1392-1398(2016).
[7] R. Koma, et al., in OFC 2016, paper M3C.6
[8] S. Kim, et al., Photon. Technol. Lett., 26.24, 2469-2472(2014).