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Demonstration of All-Digital Burst Clock and Data Recovery for Symmetrical Single-wavelength 50G PON Application using Low-bandwidth Optics

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Abstract: We experimentally demonstrated all-digital burst clock and data recovery for symmetrical 50-Gb/s/λ PON using low-bandwidth optics over the same fiber link to support over 26 dB power budget. The performances of uplink burst-mode is studied. © 2021 The Author(s)

OCIS codes: (060.2360) Fiber optics links and subsystems; (060.4252) Networks, broadcast; (060.4080) Modulation.

1. Introduction

Driven by the rapid development of cloud services, business services, and 5G wireless backhaul, the ever increasing capacity demands of access network segment grows pretty fast. The ITU-T 50G PON standard took a big step towards become a reality as consent was achieved on multiple part of the series during the ITU-T SG15 plenary meeting on April 23, 2021 [1]. PAM-4 is the most potential modulation formats for high-capacity PON systems due to its simpler DSP architecture and lower energy consumption especially for short reach optical transmission systems. For cost-effective and smooth upgrading to symmetrical 50-Gb/s/λ PON systems, the adoption of legacy low-bandwidth optics has been intensively investigated [2-5]. However, in these works, the downlink and uplink for a symmetrical PON are separately studied with different fiber links. Furthermore, the uplink transmission is studied with continuous-mode, without considering the data burst-mode. The transceivers in optical links require a high speed clock and data recovery algorithm to extract a synchronous clock and recover the received data. While for the upstream in PONs, at a symbol rate of 25 GBaud, the fast synchronization remains a significant technical challenge due to the burst-mode nature of the traffic. A sufficiently short settling time is required to ensure the data is correctly recovered. So far, no burst clock and data recovery (BCDR) has been reported on symmetrical single-wavelength 50-Gb/s PAM-4 PON based on bandwidth limited optics.

In this paper, we experimentally demonstrated all-digital BCDR for symmetrical 50-Gb/s/λ PAM-4 PON over the same fiber link at O-band, with the using of 10G DML and 15G PIN-TIA and simple DSP for the first time. The results show that over 26 dB link loss budget at HD-FEC threshold (3.8×10^{-3}) and over 28 dB at SD-FEC threshold (1×10^{-2}) in continuous-mode transmission can be achieved. The performances of uplink burst-mode compared with uplink continuous-mode are also evaluated.

2. Experimental setup

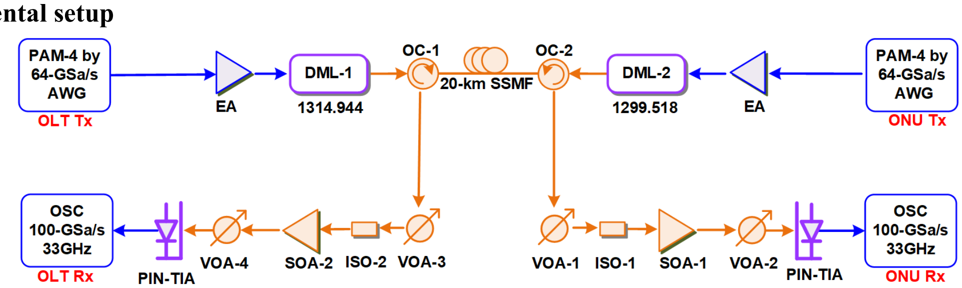

Fig.1. Experimental setup of symmetrical single-wavelength 50-Gbit/s PON system over the same fiber link at O-band.

Figure 1 shows the experimental setup for symmetrical 50 Gb/s/λ PAM-4 PON transmission over the same fiber link based on bandwidth limited optics in the O-band with simple DSP and SOAs. The downlink and uplink signals are separated by optical couplers (OC-1 and OC-2) and transmitted in the same optical fiber link. For both downlink and uplink, the 25 GBaud PAM-4 signal is generated and performed offline by MATLAB and uploaded into a 64GSa/s arbitrary waveform generator (AWG) used as a digital-to-analog converter (DAC), and then amplified by a 25 GHz linear electrical amplifier (EA) before signal modulation. For the downlink, a commercial O-Band directly modulated laser (DML-1) is used with center wavelength of 1314.944 nm, and output power of 9.62 dBm. Then, the modulated optical signal is transmitted over 20 km standard single-mode fiber (SSMF) with an average loss of 0.33 dB/km at 1310 nm. A variable optical attenuator (VOA-1) is placed after SSMF to simulate the splitter loss. In order to support larger link loss budget, Semiconductor optical amplifier (SOA-1) at the ONU is used as a pre-amplifier before direct detection. An isolator (ISO-1) is placed between VOA-1 and SOA-1 to avoid light reflection. VOA-2 is deployed to adjust the received optical power (ROP) for sensitivity measurement. Integrated PIN and TIA is used for signal detection after pre-amplification. After signal detection, the signal is captured by a 100GSa/s digital storage oscilloscope (DSO) with 33 GHz bandwidth for further offline DSP. For the uplink, the baseband PAM-4 signal is directly modulated by another commercial DML-2 at the center wavelength of 1299.518 nm. The output power of the DML-2 is 9.3 dBm. In addition, the performance parameters of the devices, such as VOA-3, ISO-2, SOA-2 AND VOA-4, used in the uplink are the same as the downlink. All commercially available SOAs have same device characteristics with a small-signal gain of 30 dB, noise figure of 7 dB and saturation output power of 17 dBm. The polarization dependent gain of both SOAs is less than 1 dB. The frequency response of the transceivers is shown in Fig. 2 (a) and (b). The optical spectra of downlink and uplink are also given in Fig. 2(c).

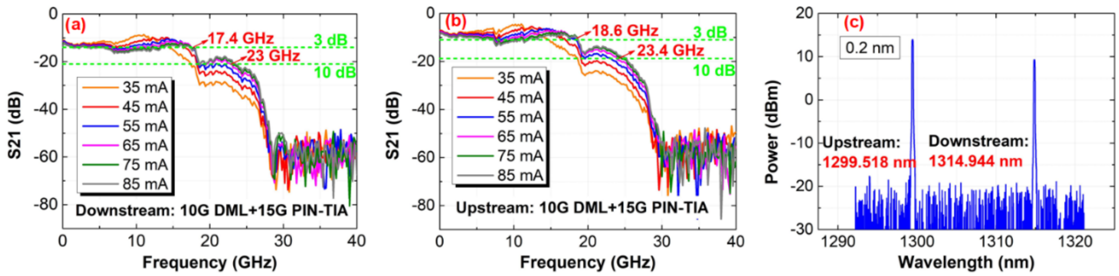

Fig. 2. The frequency response of the transceivers of 10G DML and 15G PIN-TIA for (a) downlink and (b) uplink. (c) Optical spectra of downlink and uplink.

The off-line DSP blocks at the Tx and Rx are shown in Figs. 3 (a) and (b). At the Tx side, the detailed continuous mode offline DSP includes data bits, PAM-4 mapping, resampling, normalization and downloading to AWG. At the Rx side, the captured offline data is firstly resampled to 2 samples per symbol with a matched filter, and then processed by matched filter to reduce out-of-band noise [19]. After that, a squaring time recovery is performed to remove timing offset and jitter from the data. Linear equalization based on cascaded multi-modulus algorithm (CMMA) or decision feedback equalizer (DFE) is used before bit error ratio (BER) calculation. For burst mode upstream link, the structure of burst frame is shown in Fig.3(c), which consists of three parts: frame header, payload and guard band. The frame header is designed with 25600 PAM-4 symbols for clock synchronization and data recovery. 51200 PAM-4 symbols are used as payload, and 65536 zeros are used as guard band between frames. The generation of PAM-4 signal in uplink burst mode is consistent with that in downlink continuous mode. Figure 3(d) shows the uplink burst frame captured by oscilloscope. The duration of data is 3.072 μs, and the guard band is 1.024 μs. BCDR based on squaring timing recovery algorithm is used to recover the uplink burst data clock at receiver side [6-8]. In addition, there are no pre-distortion methods such as digital pre-equalization and lookup table (LUT) pre-distortion methods at the transmitter side, and neither nonlinear equalization such as Volterra nonlinear equalization (VNE) at receiver side to simplify the DSP process and reduce the complexity.

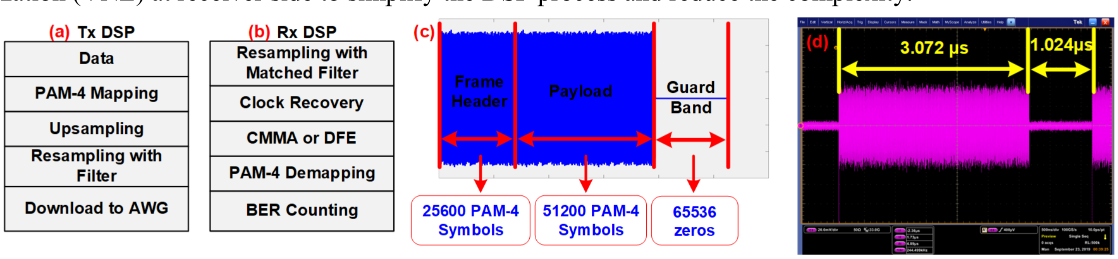

Fig. 3. (a) and (b) are the offline DSPs for PAM-4 signal generation and recovery, respectively. (c) The structure of uplink burst frame. (d) The duration of uplink burst frame captured by oscilloscope.

3. Results and discussion

The BER performance of 50 Gb/s PAM-4 PON versus ROP for downlink continuous-mode without and with 20 km fiber transmission are shown in Fig. 4. The receiver power after 20 km fiber transmission without SOA at HD-FEC and SD-FEC threshold are -8.3 dBm and -9.5 dBm, respectively. The receiver sensitivity is -17.3 dBm and -19.3 dBm at the HD-FEC threshold and SD-FEC threshold with SOA, resulting in 26.92 dB and 28.92 dB power budget with 9.62 dBm DML output power. Around 9 dB and 8.8 dB power budget improvement can be achieved by using

SOA at HD-FEC and SD-FEC threshold. There is no obvious dispersion penalty after 20 km transmission due to near zero-dispersion wavelength of DML. Insets (i)-(iii) are recovered symbols, eye diagram and histogram at -17.3 dBm ROP, respectively.

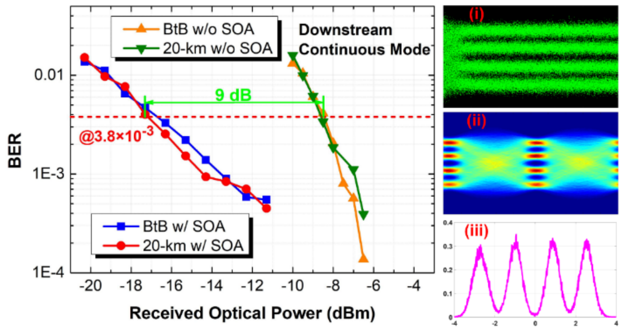

Fig. 4. The BER performance versus ROP for downlink continuous-mode. Insets (i)-(iii) are recovered symbols, eye diagram and histogram under the BER threshold at 3.8×10^{-3}.

Then, the BER performance of uplink burst-mode versus ROP is measured, as shown in Fig.5. By using the burst frame designed above, the receiver power of -7.3 dBm and -9 dBm are obtained after 20 km fiber transmission without SOA at HD-FEC and SD-FEC threshold, respectively. The achieved receiver sensitivity for the HD-FEC threshold and SD-FEC threshold are -16.3 dBm and -19 dBm by using SOA, resulting in 25.62 dB and 28.32 dB power budget. In order to compare performance in uplink burst mode and uplink continuous mode, uplink continuous-mode for 20 km fiber transmission is also tested. As shown in Fig.5, the performances of uplink burst-mode have around 1 dB loss compared to continuous-mode case. Insets (i) shows that the PAM-4 signal frame cannot be recovered without the use of BCDR in uplink burst-mode transmission. Insets (ii) is captured uplink burst frame with BCDR, and it can be observed that stable clock recovery is achieved by using the squaring timing recovery algorithm. Inset (iii) is clear eye diagram of the recovered 25 Gbaud PAM-4 signal.

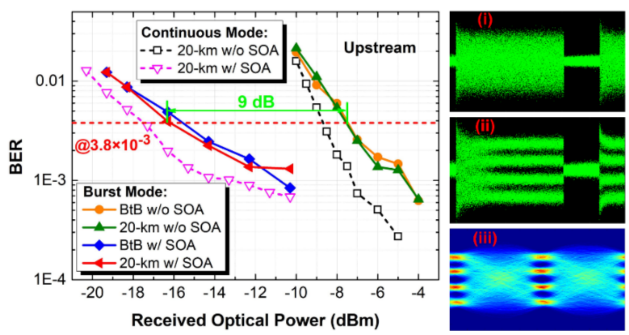

Fig. 5. The BER performance versus ROP for uplink burst-mode. Insets (i)-(ii) are recovered symbols without and with BCDR. Inset (iii) is eye diagram of recovered signal.

4. Conclusion

In this paper, a symmetric 50Gb/s PAM-4 PON uplink burst transmission over the same fiber link at O-band based on all-digital BCDR using bandwidth limited optics is experimentally demonstrated for the first time. Over 26 dB power budget for continuous-mode downlink transmission at HD-FEC threshold and over 25 dB link loss budget for burst-mode uplink transmission can be achieved at HD-FEC threshold. The performances of uplink burst-mode is around 1 dB less than uplink continuous-mode.

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