Wavelength-stable transmitter at ONU by using burst SOA for coherent TDM-PON

Acai Tan, Zhengxuan Li,* Siyu Luo, Zheng Xin, Qinyao Yang, and Yingxiong Song*
Key Laboratory of Specialty Fiber Optics and Optical Access Networks, Joint International Research Laboratory of Specialty Fiber Optics and Advanced Communication, Shanghai University, Shanghai 200444, China
*Author e-mail address: *zhengxuanli@shu.edu.cn, *herosf@shu.edu.cn*

Abstract: We propose and experimentally demonstrate a wavelength-stable upstream transmission system for coherent TDM-PON by using a burst-mode SOA at the ONU, which is capable of supporting more than 512 ONUs with high performance and reliability. © 2024 The Author(s)

1. Introduction

With the commercialization of 5G, a plethora of novel applications have emerged, including 8K and 16K video streaming, mobile X-haul, and the forthcoming all-digital transmission technology in 3D format, propelling the optical access network (OAN) towards enhanced flexibility and high-speed capabilities [1]. The point-to-multipoint topology-based passive optical network (PON) has been extensively deployed worldwide for the past two decades, primarily employing intensity modulation direct detection (IMDD) [2]. However, with the standardization of IEEE 25/50G NGEPON and ITU-T (G.9804) 50G PON, there is a growing interest in exploring higher speeds such as 100G, 200G, and beyond in PON systems [3]. Nevertheless, due to limited link budgets and the lack of digital chromatic dispersion compensation capabilities [4], IMDD faces increasing challenges when it comes to emerging 100G or higher-speed PON applications.

Coherent passive optical network (CPON) has attracted significant attention from industry scholars due to its exceptional receiver sensitivity and extended power budget. However, the complexity of the transceiver remains a challenge despite its impressive performance. Therefore, many approaches have been proposed to simplify coherent transceiver architecture and reduce receiver complexity [5,6]. In [6], the authors introduce a simplified time-interleaved phase diversity detection scheme based on single photodiode (PD) detection to demodulate multidimensional vector signals that include amplitude, phase, and polarization state. Whereas, insufficient emphasis has been placed on the requirements for the laser of the coherent receiver. The traditional time division multiplexing (TDM) PON systems mandate reducing the output optical power (OOP) of free optical network units (ONUs) to -45dBm or below to prevent crosstalk between different ONUs during upstream transmission [7]. In comparison to IMDD systems, the coherent systems with balanced receivers not only enhance signal power but also suppress a portion of laser intensity noise [8]. However, for the coherent TDM-PON, in addition to the crosstalk issue caused by relative intensity noise (RIN), there also exists a relatively high requirement for laser wavelength stability. The activation and deactivation of the laser will result in wavelength drift, which affects coherent reception performance at the optical line terminal (OLT). Therefore, stable wavelength operation is essential at the ONU in the coherent TDM-PON. The traditional control circuits such as wavelength locking and temperature control at the ONU cannot regulate the wavelength drift caused by the laser switch. Therefore, more complex control circuits are required to control the wavelength drift, however, these are too intricate for OAN applications [9]. To minimize the cost, Md Mosaddek Hossain Adib proposes a colorless coherent TDM-PON scheme based on a frequency comb laser in the OLT and a low-cost distributed feedback (DFB) laser in the ONU, which enables reliable reception of optical wavelength drift within ±4nm (±0.5THz) in the ONU [10]. This approach reduces the cost of the ONU, but at the expense of increased DSP complexity on the OLT and the ONU side.

In this paper, we propose and demonstrate a coherent TDM-PON transmission scheme. At the ONU side, a burst-mode booster semiconductor laser amplifier (SOA) is utilized. When the ONU operates, the SOA activates and acts as a power amplifier with an OOP of 10dBm. However, the SOAs of free ONUs stay off with an OOP lower than -50dBm. In this case, the laser at the ONU does not need to be switched on and off, thus avoiding wavelength drift. Besides, a complex circuit is not required to control the laser switching wavelength drift. Simulation and experimental results indicate that an OOP lower than -38dBm and -39dBm is required to realize link budgets of 29dB and 32dB when there are 512 ONUs present, respectively. In addition, the effect of noise and crosstalk can be negligible when the OOP of the free ONUs is lower than -45dBm.

2. Experiment Setup

The experimental setup is illustrated in Fig. 1. At the ONU side, a tunable semiconductor laser (Santec TSL-710) with a linewidth of 100 kHz is employed as an optical source. The 80-Gb/s PAM4 signal is generated and shaped by a root raise cosine (RRC) filter with a roll-off factor of 0.01 in MATLAB and then loaded into an arbitrary waveform generator (AWG). Subsequently, the AWG output is amplified by an electrical amplifier (EA) and fed into a 40-GHz Mach-Zehnder modulator (MZM). To control the OOP of the ONU, the modulated signal is further amplified by an SOA. At the OLT side, we adjust the polarization state via a polarization controller (PC) and use an external cavity laser (ECL) with a 500Hz linewidth and a 13.7dBm output power as a local oscillator (LO). After homodyne detection with a 25-GHz integrated coherent receiver (ICR), the signal is digitized at 80-GSa/s by a 33-GHz real-time digital signal analyzer (DSA, Keysight DSAZ594A). The received signal is processed in the offline DSP, including resampling, matching filtering, down-sampling, and equalization operations. A 35-tap feed-forward equalizer (FFE) and a 7-tap decision feedback equalizer (DFE) are applied for PAM4 signal equalization. Finally, the bit error rate (BER) is calculated. The inset (a) of Fig. 1 shows the OOP of SOA with different injection currents. When we reduce the bias current close to 0, the OOP of SOA will be lower than -50dBm. On the contrary, when the bias current exceeds 100mA, the OOP of SOA reaches greater than 10dBm. Therefore, the bust SOA can act as both a switch and an amplifier in the experiment. At the same time, since the laser remains on, the proposed scheme eliminates the need for a complex circuit to control the laser switching wavelength drift. We fix the OOP of the signal ONU at 10dBm and modify the bias current to adjust the OOP of the rest of the free ONUs.

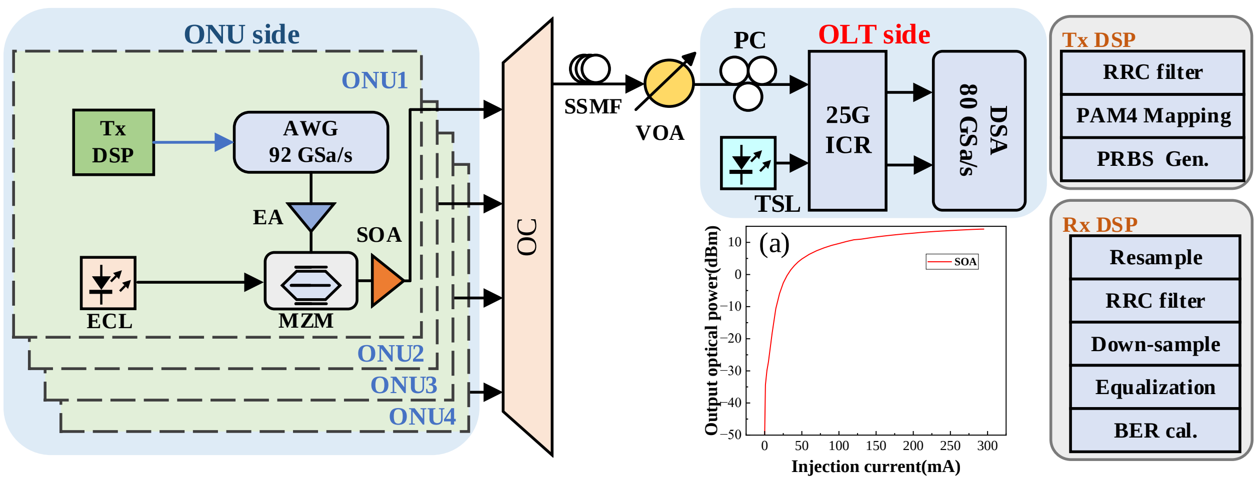

Fig. 1. Experimental setup of 80-Gb/s PAM4 coherent TDM-PON upstream transmission and inset (a) the OOP of SOA versus the injection current.

3. Results and Discussions

Fig. 2 (a) depicts the simulation BER performance of different ONUs with and without SOA. The black curve represents a point-to-point transmission with only 1 ONU. We can find that when the ROP is greater than -24dBm, the BER meets the soft decision forward error correcting (SD-FEC) threshold of 1×10^{-2}. The green and the purple curves correspond to 2 and 4 ONUs without SOA, respectively. With all ONUs active, the BER is around 0.1 and fails to reach the SD-FEC limit even if we increase the ROP to -15dBm due to the (optical beating interference) OBI noise and the crosstalk from the free ONUs. However, for the red and blue curves, by adding the SOA at the ONU side as shown in Fig. 1, we can set the OOP of free ONUs to -20dBm by adjusting the SOA current and achieve a receiving sensitivity similar to that of 1 ONU. This shows that when SOA is used, the crosstalk of free ONUs can be reduced and the wavelength drift caused by laser switching can be solved. Meanwhile, the on and off time of the burst SOA has been measured to be less than 100ns and 40ns respectively, which satisfies the on-off time requirement of the PON system [9]. To further verify the simulation and evaluate the influence of OOP on the free ONUs, we performed an experiment with 2 and 4 ONUs. Fig. 2 (b) displays the experimental BER curves of 1 ONU and 2 ONUs with different OOP of free ONUs under different ROP. We can observe that a single ONU exhibits a sensitivity of -23dBm approximately with a corresponding link budget of 33dB. For 2 ONUs, the crosstalk to the signal ONU decreases as the OOP of the free ONU decreases. Therefore, the BER performance and receiving sensitivity improve as a result of crosstalk reduction.

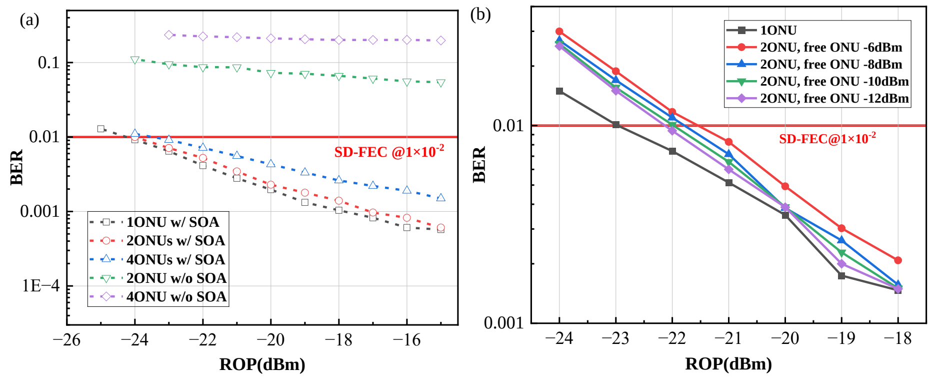

Fig. 2. (a) Simulation results of the BER performance of different ONUS with and without SOA and (b) BER performance versus ROP of 1 ONU and 2 ONUs with different OOP of free ONUs

Fig. 3 (a) shows the comparison of the BER performance and the required OOP of free ONUs for both the experiment and the simulation at the link budget of 32dB. The experimental results show that the required OOP of free ONUs for 2 and 4 ONUs are approximately -12dBm and -16dBm respectively, which indicates a difference of about 4dB. Similarly, for the simulation, the required OOP of free ONUs for 2 and 4ONUs are the same as the experimental results. These results indicate that the experiment aligns well with our simulation. Limited by the current experimental conditions, we further explore more ONU scenarios through simulation. In Fig. 3 (b), we simulate the scenario of 1 to 512 ONUs, and the number of supported ONUs can be observed by adjusting the OOP of free ONUs at different link budgets. The number of supported ONUs increases exponentially as the OOP of free ONUs decreases. For every doubling of the number of ONUs, an approximate 4dB decrease in the OOP is required for free ONUs. At link budgets of 29dB and 32dB, the corresponding required OOP of free ONUs for supporting 512 ONUs are -36dBm and -38dBm respectively.

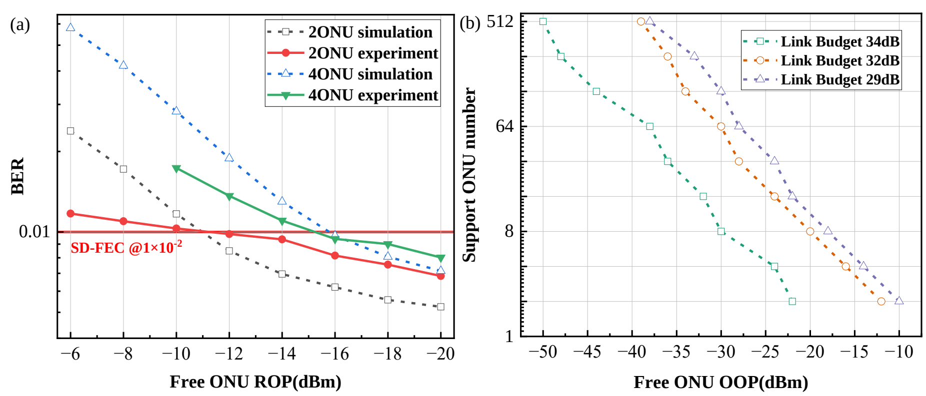

Fig. 3. (a) BER performance versus ROP of 2ONUs and 4ONUs with different OOP of free ONUs for the experiment and simulation and (b) support ONU number versus the OOP of free ONUs with different link budgets.

4. Conclusions

In this paper, we propose and experimentally demonstrate an upstream transmission scheme to solve the wavelength drift and the crosstalk problems in coherent TDM-PON systems by using a burst-mode booster SOA at the ONU. Results show that the burst-mode booster SOA enables more than 512 ONUs in the coherent TDM-PON upstream transmission scheme when the OOP of free ONUs is lower than -38dBm with a link budget of 32dB.

5. References

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