Can LAN-Wavelength Division Multiplexing Meet the Evolution of B5G/6G Terabit/s Fronthaul Networks?

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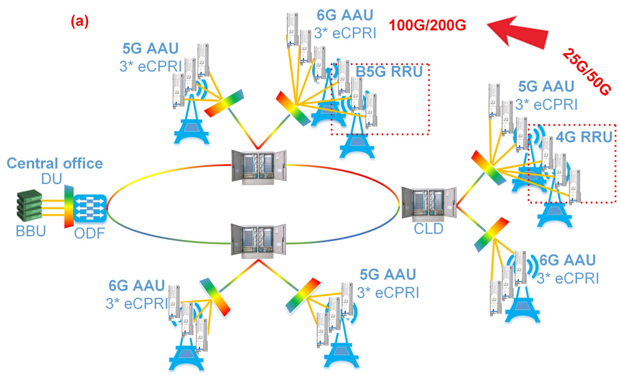
Abstract: We experimentally demonstrate a LAN-WDM access system with a record bit rate of 2 Tb/s (250 Gbit/s×8) PS-PAM-8 signal with joint equalization techniques to support the evolution of future mobile fronthaul networks with low cost. © 2022 The Author(s)

1. Introduction

With the increasing wireless data and large-scale interconnections in B5G/6G, a flexible, intelligent, and cost-effective fronthaul network is urgently needed to provide high-capacity services with hundreds of Gb/s or even Tb/s for a ubiquitous mobile society [1]. The current 5G fronthaul is based on point-to-point (PTP) intensity modulated/direct detection (IM/DD) systems, with either dedicated fiber links or wavelength-division multiplexing (WDM) links [2]. It is noted that the front-haul transport network is very sensitive to the cost of WDM interface and IM/DD which has been widely used in commercial systems. The cost of deploying a large amount of fibers is unacceptable considering the trend of constructing base stations more and more densely. Several WDM schemes have been proposed and widely deployed, including coarse WDM (CWDM), local area network WDM (LAN-WDM), and dense WDM (DWDM). In addition to higher capacity and simpler deployment, the LAN-WDM is a promising way, which can do smooth upgrade to save user deployment and spectrum resource, reduce the system cost due to the existing mature industrial chain [3]. Fig.1(a) shows the evolution of future mobile fronthaul architecture and channel schedules of LAN-WDM. Considering 3 radio remote unit (RRU) antennas for B5G and 3 active antenna unit (AAU) antennas for 6G for a base station, a total of 6 pairs of optical modules are needed. Twelve channels are used for fronthaul and consist of three parts, which are the first 4 waves and the last 4 waves of the LWDM standard and the 4 wavelengths of CWDM, as shown in Fig. 1(b). Can LAN-WDM meet the evolution from 4G/5G deployment to B5G/6G Terabit/s fronthaul networks using deployed infrastructure?

The evolution of LAN-WDM to B5G/6G fronthaul network is facing several challenges. It can be summarized up as two main transmission impairments: the nonlinear impairments from the nonlinear region of the electro-optical components, and linear impairments from the bandwidth constraint of the optoelectronic devices and fiber chromatic dispersion (CD) [4]. Fig.1(b) shows the chromatic dispersion (CD) for twelve wavelengths according to the ITU-T Recommendation G.652 standard [5]. But, there is a lack of comprehensive research about the effect of CD on the evolution of LAN-WDM to future mobile fronthaul networks.

In this work, we experimentally demonstrated an eight-channel LAN-WDM IM/DD system for B5G/6G fronthaul. We can successfully achieve a new record bit rate of 2 Tb/s (250 Gbit/s×8) PS-PAM-8 signal at SD-FEC threshold with the bit error rate (BER) of 2×10^{-2} with the aid of advanced DSPs. We also fully studied and discussed the transmission rate, transmission fiber length, and tolerance of dispersion. This is the first time to demonstrate the LAN-WDM can meet the evolution of future B5G/6G Terabit/s fronthaul networks.



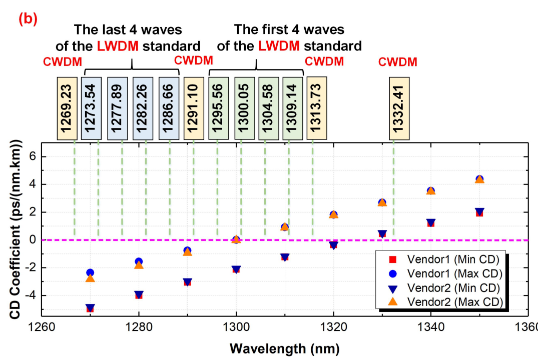


Fig. 1. (a) The evolution of future mobile fronthaul architecture; (b) the channel schedules of 12-standard-channel LAN-WDM.

2. Experimental setup

The experimental setup at the transmitter and the receiver are shown in Fig. 2(a). The transmitter consists of a high-speed arbitrary waveform generator (AWG), a DFB laser, a 65-GHz electrical amplifier (EA) and a 60-GHz intensity-modulation (IM) modulator. At the Transmitter side, the 92-GBaud PAM-*N* drive signals are generated by the 92-Gsa/s AWG with 32-GHz analog bandwidth with an offline Matlab program, and then amplified by a commercial EA before driving IM. The eight O-band DFB lasers are multiplexed by a multiplexer (MUX) through odd and even channels in the link. Three different transmission situations are considered in this experimental system: Case 1: Back-to-back case without transmission fiber; Case 2: 3-km and 5-km SMMF transmission; Case 3: To support 10-km, 15-km and 20-km SMMF transmission, the modulated optical signals are amplified by SOA before being transmitted into fiber. Then the 92-Gbaud modulated optical signal is transmitted over fiber and demultiplexed by a demultiplexer (DEMUX). Before entering the photodetector, a variable optical attenuator (VOA) is applied to adjust the received optical power (ROP) for sensitivity measurement and SOA performance testing. At the receiver side, considering attenuation in O-band transmission, we use SOA to amplify the received optical signal so that the 92-Gbaud PAM-*N* signal can be directly detected by a 100-GHz photodiode (PD) and amplified by another EA, and then captured by a real-time oscilloscope working at 128-GSa/s with 63-GHz bandwidth and processed by offline DSP. Fig. 2(b) shows the optical spectra of eight channels without modulation.

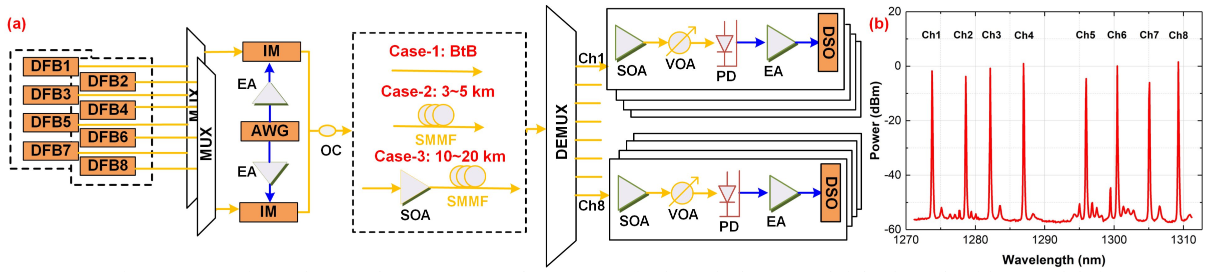


Fig. 2. (a) Experimental setup of LAN-WDM IM/DD system; (b) the optical spectra of eight channels without modulation.

In the Tx offline DSP, PAM-*N* signal with a length of 2^{18} with Gray-mapping are generated [6]. To support 92-Gbaud signals transmission, the EAs and IM at the transmitter-side may operate in nonlinear region. Therefore, we adopt probabilistic shaping (PS) scheme to reduce the average power of the transmitted signal, improve receiver sensitivity with symmetric probabilistic distribution. After two times oversampling, a square root raised cosine filter (RRCF) with 0.01 roll-off factor and digital Pre-EQ in order to adopt to further shape the signal and pre-compensate the linear impairments during transmission, the symbol sequence is resampled to one sample per symbol and loaded to the DAC at Baud-rate sampling. Pre-EQ and PS processing can result in limited peak power. Therefore, the clipping method is adopted as an effective method to reduce the peak-to-average power ratio (PAPR) of PS signals [7]. The Rx offline DSP includes resampling to two samples per symbol, squaring time recovery, nonlinear equalization (NLE) base on Volterra Filter, and decision directed least-mean-square (DD-LMS) equalizer. Finally, the BER can be calculated after PAM-*N* demodulation based on the recovered signal. Thanks to the features of low cost, high integrate ability and small physical footprint, semiconductor optical amplifier (SOA) is considered to serve as amplifier in O-band PAM signal transmission [8].

3. Results and discussion

By varying shaping factor of Maxwell-Boltzmann (MB) distribution, PS-PAM-8 symbols with different entropies (3-bit/symbol, 2.93-bit/symbol, 2.71-bit/symbol, 2.5-bit/symbol, and 2.17-bit/symbol) are generated. We keep the same total data rates (the entropy × baud rate) throughout the whole experiment, for 92-Gbaud PS-PAM-8, the corresponding total data rates are 276-Gb/s, 270-Gb/s, 250-Gb/s, 230-Gb/s, and 200-Gb/s, respectively. Bandwidth limitation is one of the most important problems for LAN-WDM to satisfy B5G/6G Terabit/s transmission. Pre-EQ is an effective method to solve this problem. Fig. 3(a) shows that Pre-EQ and clipping significantly improve the system performance. For longer distance transmission, SOA is used as a power amplifier for better performance [4]. It is necessary to optimize the parameters for SOA in such high-speed transmission system. We measure the BER performance of 200 Gb/s PS-PAM-8 in the channel 1 and 8 with different working current, which are presented in Fig. 3(b). Based on the BER results, the optimal current values are 110 mA and 60 mA for channel 1 and channel 8, respectively. It has been demonstrated that the gain provided by the SOA are also different for different wavelengths. Then, we measure the BER versus different bit rates after BTB case, 5-km fiber and 10-km fiber in the channel 1 and 8, as shown in Fig. 3(c). We can observe that 200 Gb/s, 230 Gb/s, 250 Gb/s and 270 Gb/s PS-PAM-8 can be achieved after 10 km fiber under 2×10^{-2} threshold in the channel 8. Compared to the channel 8, only 200 Gb/s and 230 Gb/s PS-PAM-8 can be achieved after 10-km fiber for the channel 1.

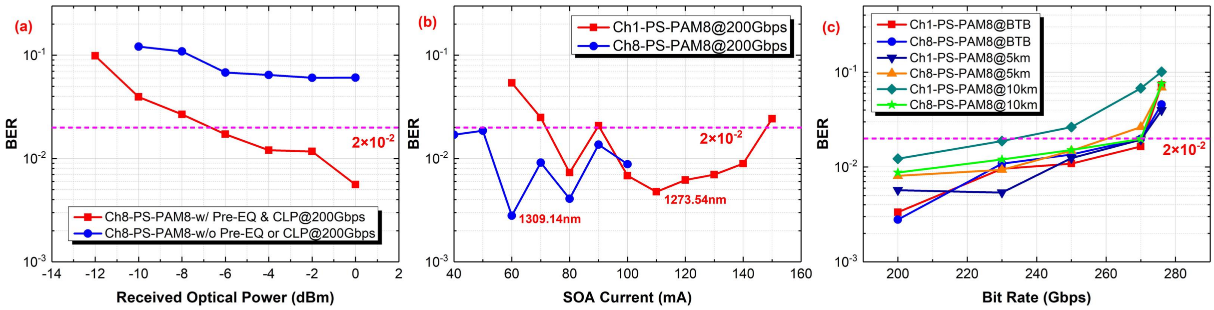


Fig. 3. (a) the BER versus ROP for BTB case w/o and w/ Pre-EQ or clipping process in the channel 8; (b) the measured BER versus SOA current in the channel 1 and 8; (c) the BER versus different bit rates with different cases in the channel 1 and 8.

In addition, we measure the BER versus fiber length for 250 Gb/s PS-PAM-8 in the channel 1 and 8, as shown in Fig. 4(a). The transmission length in the channel 1 at SD-FEC (2×10^{-2}) threshold is 5 km. The BER is general below 2×10^{-2} transferring to 20-km at SD-FEC threshold for the channel 8. Furthermore, the closer the wavelength is to 1310nm, the less the chromatic dispersion affects according to the ITU-T Recommendation G.652 standard [5], which is presented in Fig. 4(b). The maximum dispersion of channel 1 is 100 ps/nm, and the dispersion of channel 8 is nearly 25 ps/nm. Fig. 4(c) shows the BER versus different channels for 92-Gbaud PS-PAM-8 with an entropy (2.71-bit/symbol) after different transmission cases (BTB case, 5-km, 10-km, 15-km and 20-km fiber transmission). We can find that there is no problem with 8 channels transmitting 5-km simultaneously. The ability of the last four channels (channel 5 to 8) to resist dispersion is stronger after 15-km and 20-km fiber under 2×10^{-2} threshold and the channel 8 shows better performance than other channels of transmission distance. For future B5G/6G Terabit/s fronthaul networks, 5 km range is sufficient for most scenarios for dense mobile base stations deployment.

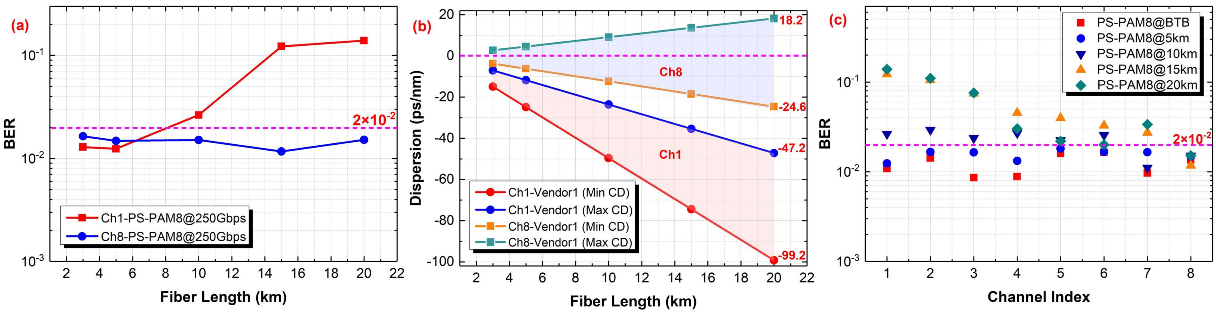


Fig. 4. (a) the BER versus Fiber Length in the channel 1 and 8; (b) the maximum and minimum chromatic dispersion versus Fiber Length for the channel 1 and 8; (c) the BER versus different channels after different transmission cases.

4. Conclusion

In summary, a LAN-WDM IM/DD system for future mobile fronthaul using bandwidth-limited optics was experimentally demonstrated based on joint equalization techniques, and successfully achieved a record bit rate of 2 Tb/s (250 Gbit/s×8) PS-PAM-8 signal with 1.6 Tb/s net rate over 5 km fiber transmission under 20% FEC threshold (2×10^{-2}) with the aid of SOA, PS technique, Pre-EQ, clipping and advanced DSPs. It is the first time to demonstrate the LAN-WDM can meet the evolution of B5G/6G Terabit/s fronthaul networks, making it a promising scheme with high capacity, low cost, and mature infrastructure.

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References

[1] Y. Fan, et al. IEEE Wireless Communications **29** (2022): 100-106.
[2] Saliou, Fabienne, et al. J. Opt Commun Netw **13** (2021): D32-D42.
[3] Dong Wang et al. ECOC 2022, We5.47-1.
[4] J. Zhang, et al. OFC, Washington, DC, USA, 2021: Th5F.4.
[5] ITU-T Recommendation G.652 (11/16), accessed on Nov. 13, 2016. [Online]. Available: https://www.itu.int/rec/T-REC-G.652-201611-I/en.
[6] G. Böchere, et al. IEEE Transactions on Communications 63, 4651-4665, (2015).
[7] J. Zhang, et al. OFC, San Diego, CA, USA, 2020: M4F.1.
[8] K. Wang, et al. IEEE Photonics Technology Letters **32**(2020): 293-296.