First Real-Time Demonstration of Symmetric 100G-PON

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Abstract: We have experimentally demonstrated real-time symmetric 100G-PON based on 10 G-class optical devices supporting 0-20 km SMF transmission without DSP. Optical dispersion compensator is employed to equalize the limited bandwidth of the system.

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1. Introduction

The current standardized next-generation passive optical network stage 2 (NG-PON2) employs time and wavelength division multiplexing (TWDM) architecture. Four wavelengths each providing a 10-Gb/s downlink data rate are stacked to provide 40-Gb/s aggregate capacity [1]. Driven by the increasing bandwidth demand of users, the research for next generation Ethernet PON is focused on the capacity of 100-Gb/s with 25-Gb/s per wavelength. The cost-effective solution to upgrade capacity is to use 10-class optical devices, therefore advanced modulation formats with higher spectral efficiency are required. Four-level pulse amplitude modulation (PAM-4) [2] and duobinary [3] formats are demonstrated to achieve ≥25-Gb/s transmission per wavelength. Formats comparison between PAM4 and duobinary format has been reported [4]. However, off-line digital signal processing (DSP) are required for the demodulation of such advanced modulation formats, which significantly increases the system cost and deployment difficulty. In comparison with high-order modulation formats, non-return-to-zero on-off-keying (NRZ-OOK) is widely used in metro and access networks since no DSP is required for signal detection, however 25G-class optical devices are still costly for PON applications. It is challenging to transmit 25-Gb/s NRZ-OOK signal based on 10G-class optical devices without DSP for signal distortion compensation. On the other hand, compared with Electro-absorption modulator (EML) and Mach-Zender modulator, directly modulated laser (DML) is preferred in PON system due to its price advantage. In our previous work, we have shown a field-trail demonstration of real-time 100G-PON with 4×25/10-Gb/s NRZ-OOK signals on downstream and upstream based on 10G-class DMLs and APDs /PINs, where an optical delay interferometer (DI) instead of off-line DSP is used to equalize the limited bandwidth of the system and compensate the fiber dispersion [5].

In this paper, we further extend the investigation and experimentally demonstrated a real-time NRZ-OOK based symmetric 100-Gb/s PON system. A single optical dispersion compensator (ODC) replacing the original delay interferometer (DI) and fiber Bragg grating (FBG) integrated on the optical line terminal (OLT) line card is used to compensate the fiber dispersion as well as equalize the limited bandwidth of the system for all downstream and upstream signals. Electrical clock/data recovery (CDR) chips on the main board are used for data generation and real-time BER measurement, therefore no DSP is required in whole system. Compared with the DI-based frequency equalization, the dispersion-supported equalization (DSE) technique is almost wavelength-insensitive therefore supporting un-cooled lasers with large wavelength drift. We evaluate the system performance using 20-km SMF, and the real-time bit error rate (BER) keeps below 1×10^{-3} for 25-Gb/s downstream and upstream signals per wavelength with as high as 37 dB and 34 dB loss budget respectively.

2. Principle

The rise/fall edge of the pulse will be broadened after transmission in a bandwidth-limited direct modulation and direct detection (DM-DD) system, resulting in the loss of high frequency components. Attributed to the positive chirp characteristics of the DMLs, the rise/fall edge of the pulse can be minimized after transmission in negative dispersion fiber with proper distance [6], corresponding to high-frequency components enhancement. We call this technique as DSE. The dispersion amount needs to be optimized to achieve the best performance. Firstly, we added different negative dispersion values to a 25-Gb/s NRZ-OOK upstream signal in BtB case using tunable dispersion compensator (TDC) and evaluated the frequency response and the BER performance. As shown in Fig. 1 (a), the high frequency response is significantly improved with the increase of the negative dispersion. It is noted that the 3-dB bandwidth changes from 9 GHz to 14 GHz and several frequency notches appear within 0~20GHz when the dispersion value exceeds -400 ps/nm. Fig. 2(b) shows the BER evolution as a function of negative dispersion value.

The BER performance improves gradually when the dispersion value changed from 0 to -150 ps/nm, and then degrades after dispersion value exceeds -150 ps/nm. In practical application, 20 km standard SMF (SMMF) in C-band introduces ~340 ps/nm positive dispersion value. Considering the performance in both BtB and 20 km transmission distance, we can set the compensation value as -440 ps/nm.

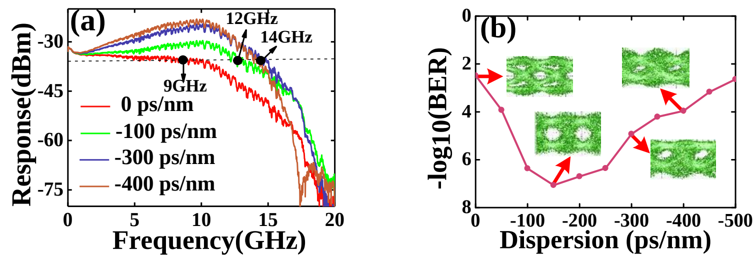

Fig. 1 (a) System frequency response and (b) BER evolution with dispersion value of 25-Gb/s NRZ-OOK signals.

3. Experimental setup

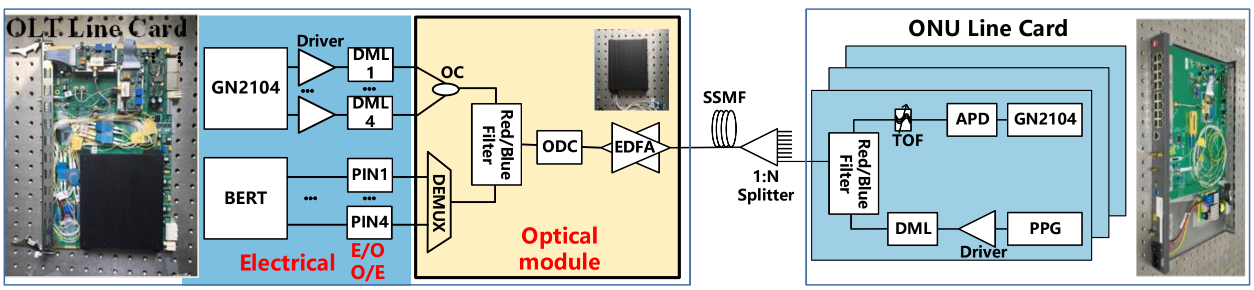

Fig. 2 Experimental setup for symmetric 100G-PON.

Figure 2 shows the experimental setup of the symmetric 100G-PON. In the OLT side, a CDR chips (Semtech GN2104) is used to generate the 25-Gb/s pseudo random binary sequence (PRBS) data. The generated NRZ-OOK signal is loaded onto the four DMLs operating at 1549.96~1554.74 nm with 200-GHz wavelengths spacing. The output optical signals are multiplexed by an optical coupler (OC). As the four upstream wavelengths are operated at 1538.98~1541.35nm with 100-GHz channel spacing, a red/blue filter is used to separate the downstream and upstream signals. Following the filter, a C-band optical dispersion compensator (ODC) with fixed dispersion of -440 ps/nm is used for DSE function for both downstream and upstream channels. Then a C-band Erbium-doped fiber amplifier (EDFA) in optical module is used to boost the signal power for power budget improvement. Note that the DI and FBG integrated in original optical module are replaced by ODC. After 20 km SSMF transmission, the signal is distributed to all ONUs by a power splitter. The receiver in the ONU consist of a tunable optical filter (TOF) used for wavelength selection and an avalanche photo diode (APD) to guarantee receiver sensitivity. Similar to the OLT side, the ONU side also employs the CDR chip GN2104 to measure the BER for 25-Gb/s downstream signal. Another red/blue filter in ONU is used to separate the downstream and upstream signals. Since the CDR chips (Silicon Labs SI5040) in the ONU and OLT line card were originally designed for 10Gbps upstream application and 25 Gb/s operation is not supported [5], we used an external pulse pattern generator (PPG, Keysight N4960A) and BERT with embedded CDR (Steligent BT6201) for upstream 25-Gb/s signal generation and detection. Another EDFA in OLT is used to compensate the power loss after uplink transmission. After equalized by ODC, the upstream signals are de-multiplexed by a wavelength de-multiplexer and sent into PINs for signal detection. Note that all the DMLs/APDs/PINS in OLT and ONUs are commercialized 10G-class devices.

4. Results

To study the influence of ODC with -440 ps/nm dispersion on the performance of 25-Gb/s NRZ-OOK signal, we measured the eye diagrams of 25-Gb/s NRZ-OOK signals at back-to-back (BtB) and 20 km reach with and without ODC in both upstream and downstream links. As shown in Fig. 3, the eye diagram is duobinary format since the 3-dB bandwidth of the downlink is 6 GHz at BtB without ODC. After equalized by ODC, the eye diagrams is converted into NRZ format. The middle eye becomes clearly open after 20 km fiber transmission with ODC. The similar signal quality improvement benefit from the DSE effect of ODC can also be observed in US direction.

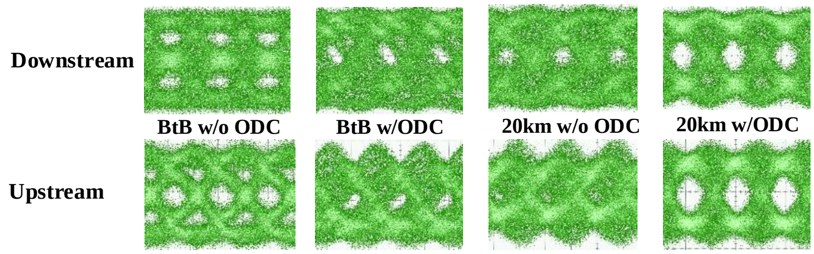

Fig. 3 Eye diagrams of 25-Gb/s upstream and downstream NRZ-OOK signals at BtB and 20 km reach with and without ODC.

Then, we evaluate the BER performance of the symmetric 100G-PON for both upstream and downstream signal at BtB and 20 km. For both the downstream and upstream links, the receivers are all followed by a CDR embedded BERT to recover the clock and count the bit errors. So the results are all based on the real-time case. For all the following BER measurement, the PRBS data sequence is set as 2^{31}-1. The BER performance subject to different fiber lengths with DSE is presented in Fig.4. As is shown in Fig.4 (a), the receiver sensitivity for all four downstream wavelengths after 20-km SMF transmission with DSE is -21 dBm. For the downstream signal, an EDFA is used to boost the optical signal power to obtain higher power budget, so we investigate the influence of launch power on the BER of 1×10^{-3} at receiver. The results are shown in Fig. 4 (b). The signal generated by DML is more tolerant to fiber nonlinearity because of the wide spectrum of DML induced by strong frequency chirp. Therefore the power launched into the fiber can exceed 10 dBm. The high power induced SPM benefits the sensitivity therefore the loss budget is improved when the input power increased. The highest loss budget for single channel is 41.8 dB at 20.8 dBm launching power of the DS channel, which is the maximal power for single channel case. For 4 channels case, the maximal launching power is 16 dBm/ch, corresponding to 37 dB loss budget. Therefore, the system can support 20 km fiber transmission and 64 users with sufficient margin. For the 25-Gb/s without DSE case, the data cannot be locked by the CDR therefore BER cannot be measured. For the upstream signal, we use the same ODC to simultaneously equalize all four wavelengths, the output power of DML is 10 dBm. As shown in Fig. 4 (c), DSE can improve the BtB sensitivity from -14 dBm to -23 dBm. After 20 km transmission with DSE, the receiver sensitivity is -24 dBm, corresponding to the loss budget of 34 dB.

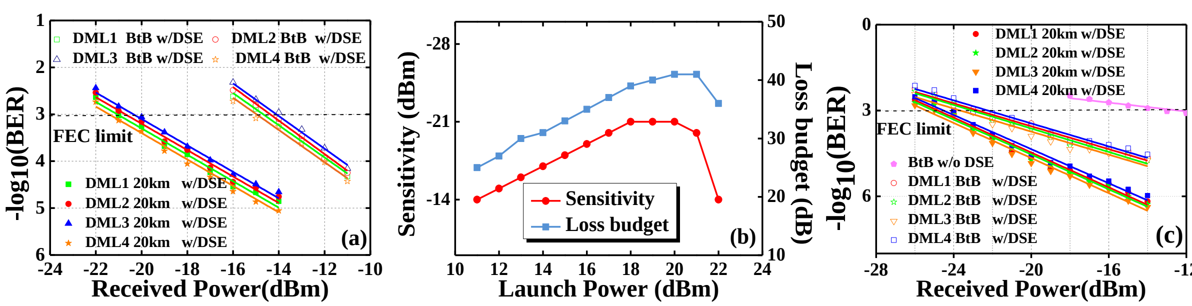

Fig. 4 BER measurement for DS signals (a) Sensitivity and loss budget for DS signal (b) BER measurement for US signal (c).

5. Conclusions

In this paper, we have experimentally demonstrated real-time symmetric 100G-PON with 4×25-Gb/s NRZ-OOK signal transmission up to 20-km SMF based on 10 Gbps DMLs and APDs/PINs. ODC is used to equalize the limited bandwidth of both upstream and downstream system. No DSP is required and real-time BER measurement is conducted. Since the ODC is wavelength-insensitive, the proposed DSE technique would be a practical and low-cost solution for symmetric 100G-PON.

6. References

[1] 40 gigabit-capable passive optical networks (NG-PON2): General requirements, ITU-T Recommendation G.989.1, 2013 http://www.itu.int/rec/T-REC-G.989.1-201303-I.

[2] H. Zhang et al., "30km Downstream Transmission Using 4×25Gb/s 4-PAM Modulation with Commercial 10Gbps TOSA and ROSA for 100Gb/s-PON," Proc. OFC, M2I.3, (2014).

[3] V. Houtsma et al., "APD-Based DuoBinary Direct Detection Receivers for 40 Gbps TDM-PON," Proc. OFC, Th4H.1, (2015).

[4] J. L. Wei et al., "Comparison of cost- and energy-efficient signal modulations for next generation passive optical networks," Opt. Express **23**(22), 28271–28281 (2015).

[5] L. Yi et al., "Field-trial of a real-time 100 Gb/s TWDM-PON based on 10G-class optical devices," Proc. ECOC, W 3.E.1, (2016).

[6] P. KREHLIK., "Directly modulated lasers in negative dispersion fiber links," *Opto-Electron. Rev*. **15**(2), 71-77 (2007).