A Novel Re-modulation Scheme to Achieve Colorless High-Speed WDM-PON with Enhanced Tolerance to Chromatic Dispersion and Re-modulation Misalignment

Jian Zhao, Lian-Kuan Chen, Chun-Kit Chan
Department of Information Engineering, The Chinese University of Hong Kong, Shatin, N. T., Hong Kong SAR, China.
Tel: +852-2609-8385, Fax: +852-2603-5032, Email: jzhao2@ie.cuhk.edu.hk

Abstract: We propose a novel re-modulation scheme using downstream OOK and upstream DPSK. A 30-km-range colorless WDM-PON without dispersion compensation and re-modulation synchronization was demonstrated within 1-dB penalty for both 10-Gbit/s downstream and 10-Gbit/s upstream signals.

OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks

1. Introduction

Wavelength division multiplexing passive optical network (WDM-PON) has aroused much attention for next-generation broadband access architecture, due to its large bandwidth and upgrade flexibility. Centralized light source (CLS) is desirable in WDM-PON because such source in central office (CO) eliminates the need of the wavelength-specific transmitters at the optical network units (ONU) and features cost reduction of wavelength management on the customer side. In the existing CLS schemes, the one using supercontinuum (SC) generation can achieve high-speed WDM-PON with upstream transmission capacity up to 10 Gbit/s [1]. However, in such scheme, synchronization between the pulses generated at CO and the data modulator at ONU is difficult. In addition, the impairment from chromatic dispersion (CD) is prominent for SC-sliced 10-Gbit/s narrow-pulsewidth signal.

Re-modulation is also a promising technique to achieve high-speed CLS WDM-PON. Compared to the scheme using SC source, such method further saves the wavelengths and transmitters by wavelength reuse. Several re-modulation schemes have been proposed, including downstream differential phase shift keying (DPSK) and upstream on-off keying (OOK), downstream frequency shift keying (FSK) and upstream OOK, downstream inverse return-to-zero (IRZ) and upstream OOK, and downstream DPSK and upstream DPSK [2-5]. However, these schemes have one or more of the following disadvantages: 1. color ONU; 2. poor CD tolerance for 10-Gbit/s upstream transmission; 3. need of re-modulation synchronization. In practice, it is much desirable to operate a high-speed WDM-PON without CD compensation and alignment monitoring for re-modulation synchronization at ONU, which reduces the implementation cost, maintenance complexity, and power consumption of the network.

In this paper, we propose a novel re-modulation scheme using finite extinction-ratio (ER) downstream OOK and upstream DPSK. We show that, despite its back-to-back penalty, such scheme can support a colorless WDM-PON of 30-km CO-ONU distance without CD compensation and re-modulation synchronization within 1-dB penalty for both 10-Gbit/s downstream and 10-Gbit/s upstream transmission. In comparison, we also show that for the previous scheme using downstream DPSK and upstream OOK, closed eyes of the upstream signal are exhibited for a 20-km-range WDM-PON without CD compensation and re-modulation synchronization.

2. Experimental Setup

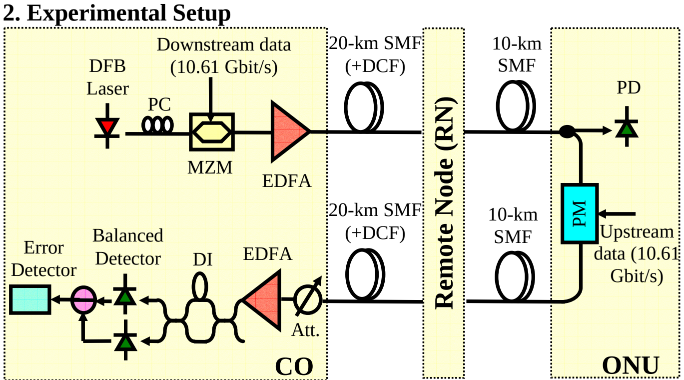

Figure 1: Experimental setup

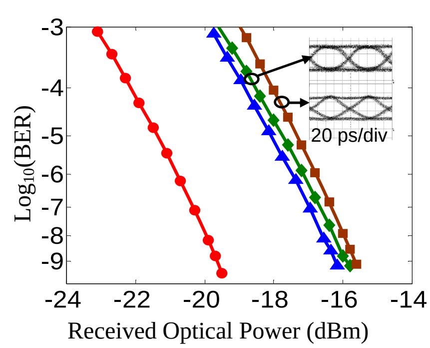

Figure 2: Performance of 10-Gbit/s pure OOK (circles), 10-Gbit/s downstream OOK of back-to-back (triangle-ups), case I (diamonds) and case II (squares).

Fig. 1 shows the experimental setup of the proposed scheme. A continuous-wave (CW) light from distributed feedback (DFB) laser was intensity modulated with finite ER by driving a Mach-Zehnder modulator (MZM) with 10.61-Gbit/s 2^7-1 pseudorandom binary sequence data. The ER was 4.9 dB. The generated downstream signal was transmitted through 20-km feeder single-mode fiber (SMF) and 10-km distribution fiber. The feeder fiber was usually CD compensated by a piece of dispersion compensation fiber (DCF) in the previous schemes [1]. In contrast, the distribution fiber cannot be CD compensated in practice because its distance varies for different ONU. Though the distribution fiber is short (<10 km), a robust WDM-PON should be capable to support data transmission through it with negligible penalty. In our experiment, two cases were considered: I) a DCF for the feeder fiber and no DCF for the distribution fiber; II) no DCF for both feeder and distribution fibers. At ONU, a portion of the downstream data was tapped off by a 50/50 coupler and fed into a 10-Gbit/s Nortel PP-C34 photo-detector (PD). The rest of the optical power was re-modulated by a 10.61-Gbit/s 2^7-1 data in a phase modulator (PM). An electrical delay was used in the experiment to adjust the misalignment between the intensity-modulated downstream optical signal and the upstream electrical data. Since ONU is wavelength independent, it is colorless. Furthermore, the use of DPSK format as upstream data relaxes the power budget of the network because the PM has 3 dB less power loss than the MZ intensity modulator and even much less power loss than the electro-absorption modulator (EAM). The re-modulated upstream signal was transmitted back to the CO, demodulated by a delay interferometer (DI) and detected by a 45-Gbit/s u^{2}t BPDV2020R balanced detector for bit error rate (BER) measurement. The use of 45-Gbit/s balanced detector for 10-Gbit/s data detection was only restricted by our equipment availability. 45-Gbit/s balanced detector was not optimized for 10-Gbit/s detection and had poor back-to-back receiver sensitivity of around -14 dBm for pure DPSK signal. Therefore, an optical pre-amplifier was used before the detector to investigate the optical-signal-to-noise ratio (OSNR) penalty.

3. Enhanced Tolerance to CD and Re-modulation Misalignment of the Proposed Scheme

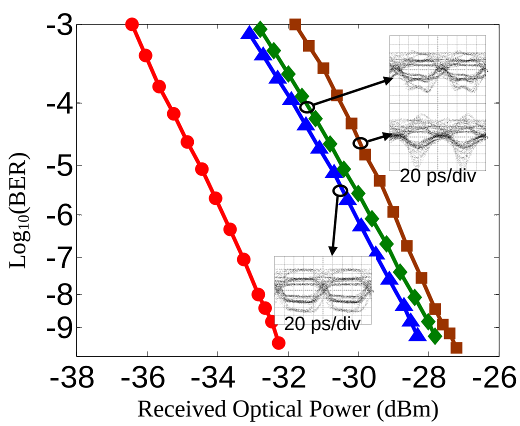

Figure 3: Performance of 10-Gbit/s pure DPSK (circles), 10-Gbit/s re-modulated upstream DPSK of back-to-back (triangle-ups), case I (diamonds), and case II (squares) with re-modulation synchronization.

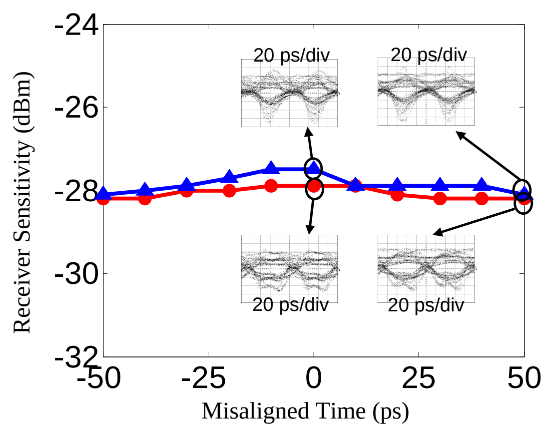

Figure 4: Receiver sensitivity of re-modulated upstream DPSK versus misaligned time for case I (circles) and case II (triangle-ups).

Fig. 2 shows performance of 10-Gbit/s pure OOK (circles), 10-Gbit/s downstream OOK of back-to-back (triangle-ups), case I (diamonds), and case II (squares). From the figure, it is shown that due to the finite ER (4.9 dB), 3.5-dB back-to-back penalty is exhibited for the downstream OOK. However, the downstream signal is robust to CD, with 0.4-dB and 0.6-dB penalty for case I and II respectively. Fig. 3 shows the performance of 10-Gbit/s pure DPSK (circles), 10-Gbit/s re-modulated upstream DPSK of back-to-back (triangle-ups), case I (diamonds), and case II (squares) with re-modulation synchronization. From this figure, we can find that the downstream OOK causes 3.9-dB back-to-back penalty to the re-modulated upstream DPSK signal. However, despite such penalty, the presence of intensity modulation has little impact on the CD tolerance of the re-modulated DPSK signal. Therefore, only 0.5-dB and 0.9-dB penalties are observed for case I and case II, respectively. Next, we investigate the tolerance of the proposed scheme to re-modulation misalignment, as shown in Fig. 4. Circles and triangle-ups represent case I and case II, respectively. From the figure, it is observed that the proposed scheme is robust to re-modulation misalignment. The sensitivity fluctuation is within 0.6 dB for both cases. The performance of the upstream DPSK is even improved a little for re-modulation misalignment, which agrees with the previous report [6].

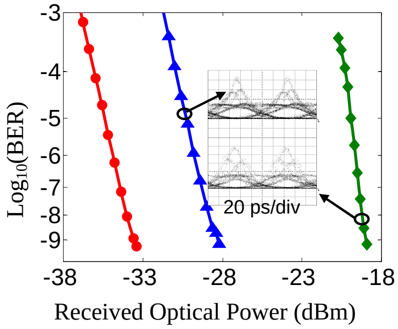

Figure 5: Performance of 10-Gbit/s re-modulated upstream OOK of back-to-back (circles), case I (triangle-ups), and CO-ONU of 20-km SMF (diamonds) with re-modulation synchronization.

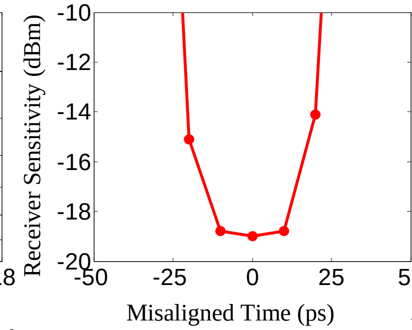

Figure 6: Receiver sensitivity of re-modulated upstream OOK versus misaligned time for CO-ONU of 20-km SMF

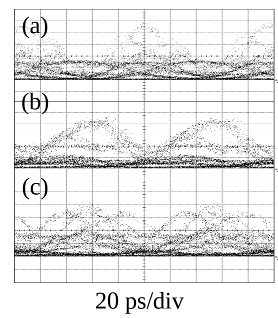

Figure 7: Eye diagrams of upstream OOK (a) with the worst misaligned time for CO-ONU of 20-km SMF; (b) with modulation synchronization for case II, and (c) with the worst misaligned time for case II.

4. Tolerance to CD and Re-modulation Misalignment of the Previous Scheme

To further show the advantages of the proposed scheme, we compare it with the previous re-modulation schemes. Intuitively, the scheme using downstream FSK and upstream OOK is vulnerable to CD because of wide spectrum of the downstream FSK [3]. On the other hand, the scheme using downstream IRZ and upstream OOK or downstream DPSK and upstream DPSK needs re-modulation synchronization [4-5]. For the scheme using downstream DPSK and upstream OOK, however, the inferior tolerance to CD and re-modulation misalignment might not be intuitive and needs experimental verification. Therefore, in this section, we will focus on the investigation of this scheme. Fig. 5 shows the performance of 10-Gbit/s re-modulated upstream OOK of back-to-back (circles), case I (triangle-ups) and CO-ONU of 20-km SMF (diamonds) with re-modulation synchronization. It is shown that although the back-to-back sensitivity of this scheme is better than that of the proposed scheme, the performance of this scheme degrades rapidly as the CD increases. This is because the presence of phase modulation induces chirp, which largely reduces the CD tolerance of the OOK signal even when the re-modulation is synchronized. Fig. 6 shows the performance of the re-modulated upstream OOK versus misaligned time for CO-ONU of 20-km SMF. Fig. 7 shows the eye diagrams of the upstream OOK (a) with the worst misaligned time for CO-ONU of 20-km SMF; (b) with modulation synchronization for case II; and (c) with the worst misaligned time for case II. The worst misaligned time leads to chirp in the middle of the time slot of the upstream OOK. Compared to the case of re-modulation synchronization where the chirp is between the time slots, the CD tolerance of the upstream OOK is further reduced. Therefore, as shown in Fig. 5 & 7, for CO-ONU of 20-km SMF, the eye with modulation synchronization is still open while the one with the worst misaligned time is completely closed. For case II, no matter the modulation is synchronized or not, the eyes are both closed, as shown in Fig. 7. These results confirm the advantages of the proposed scheme in its enhanced tolerance to CD and re-modulation misalignment.

5. Conclusions

We experimentally showed that for the previous scheme using downstream DPSK and upstream infinite-ER OOK, despite its better back-to-back sensitivity, closed eye was exhibited for the upstream signal for CO-ONU of 20-km SMF without CD compensation and re-modulation synchronization. A novel re-modulation scheme using finite-ER downstream OOK and upstream DPSK is proposed. By using this technique, a 30-km-range high-speed colorless CLS WDM-PON without CD compensation and re-modulation synchronization was achieved within 1-dB penalty for both 10-Gbit/s downstream and 10-Gbit/s upstream transmission. This work was partially supported by a research grant from the Hong Kong Research Grants Council of Hong Kong, SAR, Project No. CUHK4110/05.

References

[1] B. Zhang, et al., "A simple high-speed WDM PON utilizing a centralized supercontinuum broadband light source for colorless ONU", *OFC*, OTuC6 (2006).

[2] W. Hung, et al., "An optical network unit for WDM access networks with downstream DPSK and upstream re-modulated OOK data using injection-locked FP laser", *PTL*, **15**, pp. 1476-1478 (2003).

[3] N. Deng, et al., "A novel wavelength modulated transmitter and its application in WDM passive optical networks", *OFC*, MF79, (2004).

[4] G. Lu, et al., "Use of downstream IRZ signal for upstream data re-modulation in a WDM passive optical network", *OFC*, OFI8 (2005).

[5] Y. Tian, et al., "Optical VPN in PON based on DPSK erasing/rewriting and DPSK/IM formatting using a single Mach-Zehnder modulator", *ECOC*, Tu4.5.6 (2006).

[6] J. Zhao, et al., "Tolerance of misalignment between ASK and DQPSK modulation in ASK/DQPSK orthogonal modulation systems", *OECC*, 5F3-3 (2006).