Enhancement of Wavelength Offset Tolerance for Downstream DPSK Signals Demodulation in 10-Gb/s WDM-PONs

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***Abstract*— Enhanced wavelength offset tolerance is achieved by using a 25-ps DI's destructive port for the 10-Gb/s downstream DPSK signal demodulation in WDM-PONs. The constructive port output is used for upstream remodulation to simplify ONU structure.**

I. Introduction

Wavelength-division-multiplexed passive optical network (WDM-PON) is a promising technology for the next-generation access networks, due to its large bandwidth and upgrade flexibility [1]. Re-modulation of downstream signal to generate upstream signal is an attractive solution for low-cost implementation of WDM-PON, as it eliminates the need of wavelength-specific transmitters and wavelength management at the optical network units (ONU) [2]. The key issue of the re-modulation scheme is how to suppress the crosstalk between the upstream and the downstream data. One straightforward approach is to reduce the extinction ratio of the downstream signal, at the expense of downstream performance degradation. A more elegant approach has been proposed by using downstream differential phase-shift keying (DPSK) and upstream on-off keying (OOK) [3]. As the modulation format for downstream is of constant amplitude, it can be reused for upstream remodulation. In addition, the constant-intensity nature of the DPSK modulation format reduces various nonlinear phenomena during transmission, thus improving the system power budget. At the ONU in [3], a power splitter is needed for the separation of the downstream signal and the signal for re-modulation. Only one output port of the delay interferometer (DI) is used as balance detector is expensive for access networks. The power from the other output port of the DI is wasted.

In this paper, we propose the use of the destructive port of a DI with partial-bit delay to demodulate the 10-Gb/s downstream DPSK signal with enhanced tolerance to wavelength offset between the laser source and the DI, whereas the constructive port output is used as the source for upstream re-modulation. Thus, the ONU structure is also simplified, as a power splitter is saved. The DI is used for both downstream signal demodulation and the separation of the downstream signal and the upstream source. Proper termination required for the unused output port of DI in [3], can also be eliminated.

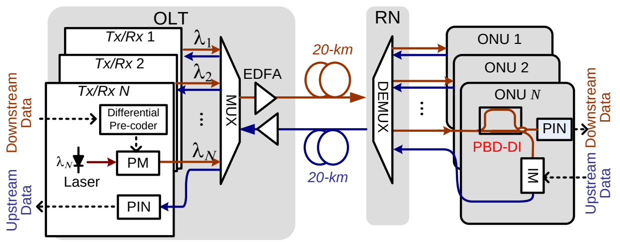

Fig. 1. WDM-PON architecture using the proposed simplified ONU structure with partial-bit-delay DI (PBD-DI).

II. Principle and System Architecture

Fig. 1 illustrates the architecture of a WDM PON using downstream DPSK and upstream OOK with our proposed ONU structure. For each downstream wavelength at the OLT, differentially precoded data is used to drive an optical phase modulator (PM) to generate the downstream DPSK signal. After transmission, the downstream signal from the OLT is wavelength routed by an arrayed waveguide grating (AWG) at the remote node (RN) toward different ONUs. At an ONU, the downstream DPSK signal is demodulated by the destructive port of the DI with partial-bit delay between two arms before direct detection, while light from the constructive port is fed into an optical intensity modulator (IM) for upstream data re-modulation.

Assume the delay between two arms of the DI is kT, where $0<k<1$ and T is the bit-period. As the relative delay of the DI used at ONU is shorter than one bit period, the leading part of any bit will interfere with the trailing part of the previous bit at the DI output port within the overlap duration of kT. In the remaining $(1-k)T$ part, the two signals on the two arms of DI are from the same bit, thus leading to a constant 1 and 0 for the constructive and destructive ports, respectively. Thus, the output from the destructive port of the DI should be return-to-zero (RZ) shaped, whereas the output from the constructive port should be inverse-return-to-zero (IRZ) shaped. The IRZ shaped output from the constructive port of the DI, which always has optical power in each bit, can be readily re-modulated by the upstream data. As the phase error within DI, caused by the wavelength offset between the laser source and the DI, is proportional to the relative delay of the DI [4], using partial-bit DI to demodulate the downstream DPSK signal is more robust to wavelength offset. There is only small variation in the

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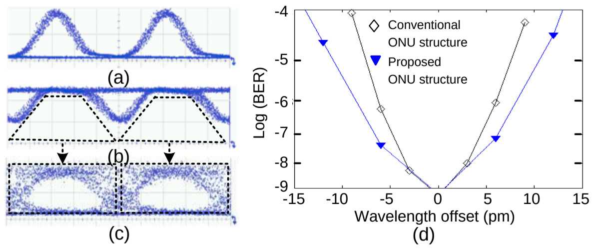

Fig. 2. Eye diagrams of (a) the demodulated downstream 10-Gb/s DPSK signal from the destructive port of the 0.25-bit DI, (b) IRZ-shaped output from the constructive port of the 0.25-bit DI , (c) the detected upstream OOK signal. Time scale: 20 ps/div. (d) BER degradation (from 10^{-9}) caused by wavelength offset between the laser source and the DI.

system power budget as will be discussed in the next section.

III. Experimental Demonstration

We have experimentally demonstrated the proposed ONU structure based on the architecture shown in Fig. 1. At the OLT, continuous-wave (CW) lights at 1549.3 and 1550.1 nm were coupled into a PM driven by a 10-Gb/s 2^{31}-1 pseudorandom binary sequence (PRBS). The phase modulated output was then amplified to 4 dBm per channel and was coupled into a 20-km dispersion-shifted fiber to emulate the dispersion-compensated transmission between the OLT and the RN. At the RN, an AWG with a channel spacing of 0.8 nm and a 3-dB bandwidth of 0.35 nm was used to separate the two channels. The 1549.3-nm channel was input into a DI with 25-ps relative delay. The demodulated downstream data from the destructive port of the DI was then directly detected by a 10-Gb/s p-i-n receiver. Light from the constructive port was combined with the 1550.1-nm channel from the AWG via a 3-dB coupler and then fed into an optical IM, driven by a 10-Gb/s 2^{31}-1 PRBS as the upstream data, before being transmitted back to the OLT via another piece of 20-km dispersion-shifted fiber. The two channels were modulated by the same IM at the ONU and the same PM at the OLT due to equipment availability.

As the two WDM channels had very similar performance, only the eye diagrams and bit error rate (BER) measurements for the 1549.3-nm channel are shown. Fig. 2(a) shows the clearly opened RZ-shaped eye diagram of the demodulated downstream DPSK signal from the destructive port of DI. Fig. 2(b) shows the IRZ-shaped output from the constructive port. As there is constant optical power in each bit for upstream re-modulation, as denoted by the area of the dashed trapezoid in Fig. 2(b), the detected upstream signal shows wide-open eye diagram in Fig. 2(c). By using the proposed ONU structure, the DPSK signal demodulation is less sensitive to wavelength offset between the laser source and the DI, as shown by the smaller slope in Fig. 2(d). It was measured that for less than 1-dB power penalty at BER of 10^{-9}, the DPSK signal can tolerate 25% larger wavelength offset, by using the proposed ONU structure than the conventional one. The BER measurement results are shown in Fig. 3. After 20-km transmission, around 0.5-dB and 1-dB power penalty at BER of 10^{-9} are observed for the downstream and the upstream data, respectively.

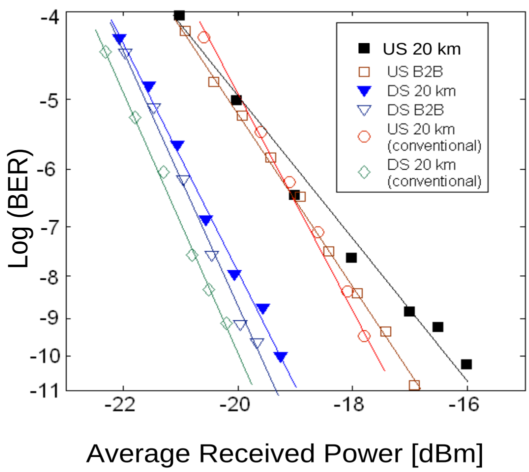

Fig. 3. BER measurement results for both down- and up-stream signals.

For comparison, we also measured the BER curve using the conventional ONU structure as in [3], where the downstream DPSK signal was demodulated by a DI with one-bit delay, and a power splitter was used to tap part of the downstream DPSK signal as the source for upstream re-modulation. Around 0.8-dB and 1.2-dB power penalty at BER of 10^{-9} were observed for the downstream and the upstream data, respectively, using the proposed ONU structure. Nevertheless, the major power penalty of the upstream data can be compensated by the reduced insertion loss of the proposed ONU. In the experiment, the measured insertion loss of the destructive port was 4 dB and 7.6 dB for the 1-bit and 0.25-bit DI, respectively. The measured insertion loss of the constructive port for the 0.25-bit DI was 2.4 dB. As the 3.5-dB insertion loss of the power splitter is eliminated in the proposed ONU structure, power budge for the proposed ONU structure was only reduced by around 0.9 dB and 0.1 dB for the downstream and the upstream transmission, respectively.

IV. Conclusions

We have demonstrated the novel use of a partial-bit DI's destructive port to demodulate the 10-Gb/s downstream DPSK signal with enhanced tolerance to wavelength offset. Meanwhile, the IRZ-shaped output from the constructive port can be readily used for 10-Gb/s upstream re-modulation to simplify the ONU structure.

References

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