Signal Remodulation PON without Power Sacrifice using PolSK

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Abstract *We propose and demonstrate a novel signal remodulation scheme using PolSK with high extinction-ratio. Error-free was achieved in a 20km reach 10Gb/s DWDM-PON without dispersion compensation.*

Introduction

DWDM passive optical networks (PONs) offer a potentially cost effective way of increasing user bandwidths. A cost-effective deployment would employ the same components in each optical networking unit (ONU), which should thus be independent of the wavelength assigned by the network. Optical carriers are distributed from head-end office to produce the upstream signals. Remodulation of downstream to generate upstream signal further reduces the cost by wavelength reuse. Several remodulation schemes have been proposed, including using both downstream and upstream on-off keying (OOK) [1]; downstream differential phase shift keying (DPSK) and upstream OOK [2]; downstream inverse return-to-zero (IRZ) and upstream OOK [3]; downstream low extinction-ratio (ER) OOK and upstream DPSK [4]. However, these approaches are limited by various combinations of high chirp [1, 2] and limited speed [1-3]. For the IRZ [3] and the low-ER OOK [4] remodulations, the residual continuous wave (CW) background between IRZ pulses and the finite ER in the OOK are required respectively, to provide high enough optical power for the integrity of upstream remodulation. These greatly reduce the back-to-back (B2B) receiver (Rx) sensitivity and limit the maximum reach and split ratio of the PON. Here, we propose and demonstrate a novel wavelength remodulation scheme using polarization shift keying (PolSK) in both upstream and downstream for 10Gb/s DWDM-PONs. PolSK is considered as one of the promising modulation formats for future optical networks. PolSK transceiver [5] has been demonstrated; and 40Gb/s PolSK modulator [6] has been commercially available. The proposed remodulation scheme using PolSK enables high ER signals in both directions. A 20km-reach PON without dispersion compensation was demonstrated and 1dB penalty was added during the remodulation process.

Experiment

Fig. 1 shows the experimental setup. The downstream 10-Gb/s PolSK signal was generated by launching a CW (1548 nm) at 45° into a $LiNbO_3$ phase modulation (PM) electrically driven by a nonreturn-to-zero (NRZ) data (D_{down}) to produce the PolSK signal. It was transmitted through a 10-km feeder single-mode fiber (SMF) and 10-km distribution/drop fiber. The optical fiber cannot be fully dispersion compensated in practice, hence no dispersion compensation was used. Dual-feeder fiber architecture was employed to reduce Rayleigh backscattering reflecting towards the head-end Rx, while maintaining the merits of single distribution/drop fiber. The downstream PolSK was launched into the ONU via an optical circulator (OC), and 10% of optical power was received by an optically pre-amplified Rx, consisted of a polarization beam splitter (PBS) for PolSK demodulation, and a 10Gb/s PIN photodiode. The rest of the optical power was launched into a PM to generate the upstream signal. To rewrite the phase information onto the downstream optical signal, $D_{down} \oplus D_{up}$ was applied to the PM, where $\oplus$ is the exclusive-OR (XOR) logic operation. Using the fact that $D_{down} \oplus D_{down} = 0$; $0 \oplus D_{up} = D_{up}$; and the downstream optical signal is launched at the appropriate angle to the PM [using a polarization controller (PC)] such that the phase information is rewritten and only D_{up} remains, hence, upstream PolSK can be generated. The timing and polarization alignments to generate the upstream signal are crucial, and they can be controlled using electrical buffer and polarization tracking respectively [7].

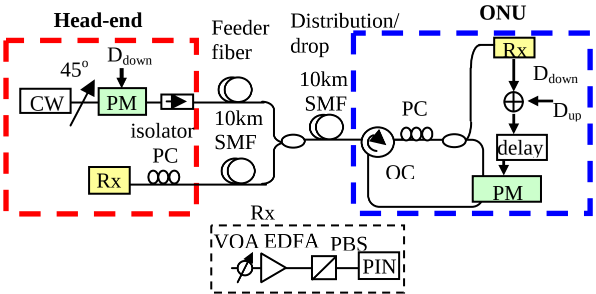

Fig. 1 Experiment of DWDM-PON. PM: phase modulator, PC: polarization controller, PBS: polarization beam splitter. Inset: optical pre-amplified receiver (Rx).

Results and Discussion

Numerical analysis was performed to confirm the experimental results. Fig. 2 shows the 10Gb/s experimental bit-error rate (BER) measurements of the proposed scheme, with the experimental and simulated PolSK eye-diagrams of downstream (ER=10dB) and upstream (ER=7dB) signals. Power penalty of 1.7dB at BER of 10^{-9} was measured for the demodulated PolSK downstream signal at the ONU after the transmission of 20km SMF without dispersion compensation. Power penalty of 4.7dB (compared with the B2B) was measured for the

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remodulated upstream PolSK at the head-end Rx, due to the accumulated dispersion of 40km SMF and the remodulation process at the ONU. To estimate the power penalty introduced during the remodulation, only 40km transmission of PolSK signal was performed, showing the remodulation process introduced an additional 1dB penalty. There is a good match between the experiment and simulation in terms of Rx sensitivity penalties and eye-shapes.

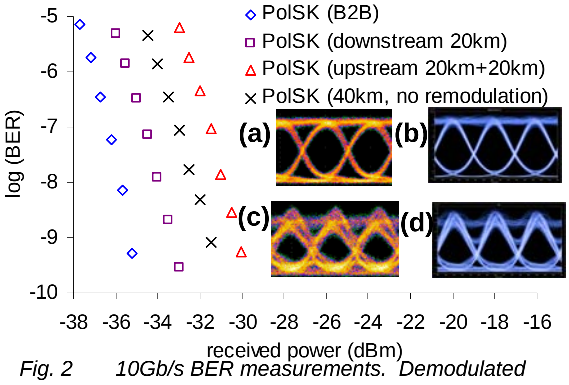

Fig. 2 10Gb/s BER measurements. Demodulated PolSK (a) experimental, (b) simulated downstream eyes; and (c) experimental, (d) simulated upstream eyes.

Fig. 3(a) and (b) show the Rx sensitivity penalties at BER of 10^{-9} induced to the PolSK upstream signal by timing misalignment between the downstream PolSK and the applied electrical signal to the PM in the ONU; and the polarization misalignment between the downstream PolSK and the principal axis of PM respectively. The tolerance for 1-dB penalty is ~20 ps (similar to other reported remodulation [4]) for the timing misalignment and ~16^o for the polarization misalignment. Since the random birefringence of buried optical fiber networks typically causes only 2^o to 10^o fluctuations in the polarization angles of the propagating signals [8], a slow dynamic polarization control may be used to compensate the polarization fluctuations. It is worth to mention that launching higher optical power is desirable for PON application in order to increase the reach and the split ratio of PON. We experimentally show that PolSK signal has much higher tolerance to stimulated Brillouin scattering (SBS) and allows at least ~3 dB higher input power than that of NRZ.

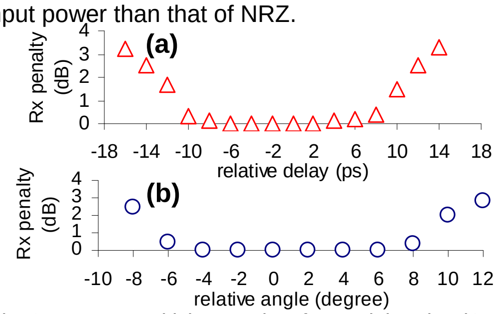

Fig. 3 Rx sensitivity penalty of remodulated PolSK versus (a) timing and (b) polarization misalignment in ONU.

To further show the advantages of the proposed scheme, we compared it numerically [with and without balance detection (BD)] with the previously proposed remodulation schemes, including downstream IRZ and upstream OOK [3]; downstream low ER-OOK and upstream DPSK [4]. For the BD of PolSK signals, a balance PD was connected at the two orthogonal output ports of the PBS inside the Rx. The simulations were performed at 10Gb/s for all cases and the Rx sensitivities were compared with the NRZ modulation (Table I) at B2B. For the proposed PolSK downstream and upstream scheme, no power penalty was observed when compared with NRZ signal at B2B, and in principle, Rx sensitivity improvement of 3dB was observed if BD was used. For the IRZ-and-OOK remodulation, power penalty of 6.8dB was observed in the IRZ due to its high residual CW background to provide enough optical power for the remodulation of upstream OOK. The upstream OOK showed a negative power penalty of 0.5dB due to the return-to-zero (RZ)-like upstream signal, enhancing the Rx sensitivity. For the low-ER OOK-and-DPSK scheme, a low-ER OOK downstream signal was required to provide enough residual optical power for the upstream remodulation. Hence, a high power penalty of 7.2dB was observed. Error free DPSK upstream detection was not possible unless BD (power penalty of 10dB) was used owing to the conversion of the low-ER OOK to amplitude fluctuation in the upstream DPSK.

	PolSK (down)/ PolSK (up)	PolSK (down) / PolSK (up) BD	IRZ (down) /OOK (up)	Low ER-OOK (down)/ DPSK (up)	Low ER-OOK (down)/ DPSK (up) BD
Rx penalty (down)	0dB	-3dB	+6.8dB	+7.2dB	+7.2dB
Rx penalty (up)	0dB	-3dB	-0.5dB	Error floor at BER 10^{-8}	+10dB

Table I Comparison of different remodulation schemes at B2B Rx penalty with NRZ signal. BD: balance detection.

Conclusions

We propose and demonstrate a novel wavelength remodulation scheme using PolSK in both downstream/upstream signals with high ER. Error-free operation was achieved in a 20-km-reach 10-Gb/s DWDM-PON. Comparison with other wavelength remodulation schemes shows the proposed scheme may be a potential candidate for next generation wavelength reuse DWDM-PONs.

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