Signal remodulation high split-ratio hybrid WDM-TDM PONs using RSOA-based ONUs

C.W. Chow, C.H. Yeh, C.H. Wang, F.Y. Shih and S. Chi

A signal remodulation scheme using DPSK downstream and OOK upstream signals for high split-ratio hybrid WDM-TDM PONs is proposed and demonstrated. Colourless and polarisation insensitive operations are implemented using RSOA at the customer side. By comparing with previous similar remodulation schemes, the proposed scheme can mitigate the phase-to-intensity and polarisation tracking issues. The driving current and launched power of the RSOA are also studied, showing that it could be a promising candidate for the next generation of high split-ratio hybrid WDM-TDM PONs.

Introduction: Future access networks will have to meet the ever-increasing bandwidth demand to provide broadband services. Hybrid wavelength division multiplexed–time division multiplexed (WDM-TDM) passive optical networks (PONs) [1] have been proposed to achieve this target. Using a centralised light source at the head-end office is emerging as a cost-effective deployment. This is because the same colourless optical networking units (ONUs) can be used for all the customers in the PONs. Signal remodulation of the downstream signal to produce the upstream signal can further reduce the cost owing to wavelength reuse. Recently, a signal remodulation scheme using an injection-locked Fabry-Perot laser diode (FP-LD) was proposed [2]. The FP-LD inside the ONU was injection locked by the downstream 10 Gbit/s on–off keying (OOK) signal, which can then be modulated to produce the 1 Gbit/s upstream OOK signal. However, this scheme needed relatively high injection power to achieve injection locking and sacrificed the extinction ratio (ER) of the downstream signal for the integrity of the upstream signal. A downstream signal using differential phase shift keying (DPSK) was then proposed [3] to solve the ER limitation problem. However, injection locking using the DPSK signal suffered from amplitude fluctuations owing to the phase-to-intensity conversion in the upstream signal, and reduction of the phase modulation depth in DPSK was used [3]. WDM-PON using DPSK downstream and OOK upstream has also been proposed [4, 5]. However, relatively high power penalty was observed in the upstream signal since the downstream signal was demodulated before launching into the reflective semiconductor optical amplifier (RSOA) [4] and high insertion loss was introduced by using an electro-absorption modulator (EAM) [5].

In this Letter, we propose and demonstrate a signal remodulation high split-ratio WDM-TDM PON using downstream DPSK and upstream OOK with RSOA-based ONU. RSOA is generally considered as a potential low-cost and relatively high data rate device for ONU in the next generation colourless PONs, and recently, 10 Gbit/s RSOA has been implemented [6]. Different operating conditions of the RSOA are also studied.

Experiment: Fig. 1 shows the architecture of the proposed WDM-TDM PON. A continuous wave (CW) at 1548 nm was encoded by DPSK data via a phase modulator (PM) at 10 Gbit/s pseudorandom binary sequence (PRBS) $2^{31}-1$. The downstream signal was transmitted through 10 km feeder singlemode fibre (SMF) via a pair of arrayed waveguide gratings (AWG) (Gaussian shaped, 3 dB width of 50 GHz) and 10 km of distribution/drop fibre. Dual-feeder fibre was used to mitigate the impairments introduced by Rayleigh backscattering by simply reducing the backscattered power that reaches the head-end receiver (Rx), while providing the advantages of using single distribution/drop fibre to reach users [7]. A fixed optical attenuator (FA) of −21 dB was used to emulate the 128 split-ratio of the PON. The 21 dB loss is a theoretical value of a 1 × 128 passive splitter. At the ONU, 10% of optical power was taped and received by an optically pre-amplified Rx. The constant intensity downstream DPSK signal was demodulated by a 1-bit delayed interferometer (DI). The Rx consisted of a variable optical attenuator (VOA), erbium-doped fibre amplifier (EDFA), and a 10 Gbit/s *pin* photodiode (PD), as shown in the inset of Fig. 1. The EDFA was used to increase the receiver sensitivity. However, including an EDFA in each ONU could be expensive. It can be located in the fibre link to compensate for losses due to AWGs, fibres and splitter; and every ONU can share the cost. The rest of the downstream optical signal was then launched into the RSOA, which was driven by a 2.5 Gbit/s non-return-to-zero (NRZ) data at PRBS $2^{31}-1$, for signal remodulation.

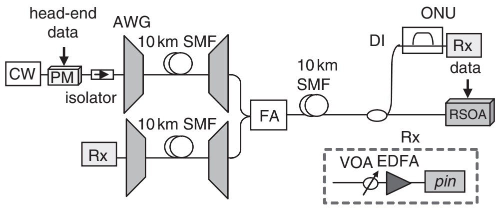

Fig. 1 *Architecture of high split-ratio WDM-TDM PON using DPSK downstream and OOK upstream signals*

PM: phase modulator, SMF: singlemode fibre; VOA: variable optical attenuator; AWG: arrayed waveguide grating; DI: delayed interferometer; EDFA: erbium-doped fibre amplifier; FA: fixed attenuator
Inset: optically pre-amplified receiver (Rx)

Results and discussion: Fig. 2 shows the bit-error rate (BER) measurements of the downstream and upstream signals at back-to-back and after 20 km transmission. The corresponding eye diagrams are shown in the insets. Error-free operations are observed in each case with clear open eyes. We measured about 1.5 dB power penalty in the downstream DPSK signal. We observed negligible power penalty in the upstream OOK signal after the 20 km transmission. Less than 1 dB power penalty was observed if the downstream CW was used instead of the DPSK signal when launched into the RSOA to generate the upstream OOK signal.

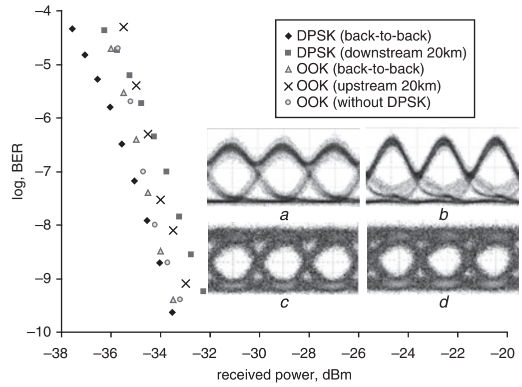

Fig. 2 *BER measurements of WDM-TDM PON*

Insets: eye diagrams of *a* demodulated DPSK at back-to-back, *b* DPSK after 20 km transmission, *c* OOK at back-to-back and *d* OOK after 20 km transmission

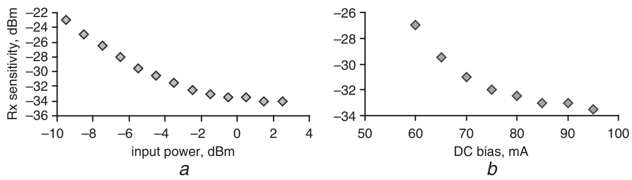

Fig. 3 *Rx sensitivities of upstream remodulated OOK signal*

a Under different injected powers when RSOA DC biased at 95 mA
b Under different DC biases when input downstream signal to RSOA is at ~0 dBm

We also studied the different operation conditions of the RSOA in this network architecture based on the setup in Fig. 1. The input was the DPSK signal (without demodulation), and the RSOA was electrically driven at 2.5 Gbit/s NRZ data. The RSOA has a small-signal gain of 20 dB, noise figure of 7 dB, saturated power of 2 dBm and polarisation dependent gain of about 1 dB. Fig. 3*a* shows the Rx sensitivities of the upstream OOK signal under different launched powers when the RSOA was DC biased at 95 mA. We can observe that the Rx sensitivity is minimum, and starts to saturate at a launched power of −2 dBm. We can achieve Rx sensitivity of −23 dBm when the input power to the RSOA is about −10 dBm. Fig. 3*b* shows the Rx sensitivities of the upstream OOK signal under different DC biases, when the input downstream signal to the RSOA is at ~0 dBm. We can also see that the optimum DC driving current to the RSOA is ≥85 mA.

One advantage of this scheme is that it is insensitive to the polarisation of the input downstream DPSK signals. We observed that the input polarisation dependence was about 1 dB, which was due to the polarisation dependent gain of the RSOA. Another advantage of this scheme is that synchronisation between the downstream and upstream signals is not required. Fig. 4 shows the measured Rx sensitivities of the upstream OOK signal under different delays of the downstream DPSK signal when the RSOA was DC based at 95 mA and the input optical power was about 0 dBm. Here, we also studied the phase-to-intensity effect by replacing the RSOA inside the ONU with another colourless ONU: FP-LD. Its threshold current is about 10 mA, and it was DC biased at 30 mA. Figs. 5*a* and *b* show the time traces at the output of the RSOA and FP-LD, respectively, after being launched with the downstream DPSK signal. In both cases, the electrical 2.5 Gbit/s NRZ data applied to the RSOA or FP-LD was removed for proper display of the time traces. We can see clearly the high amplitude fluctuation in the FP-LD case.

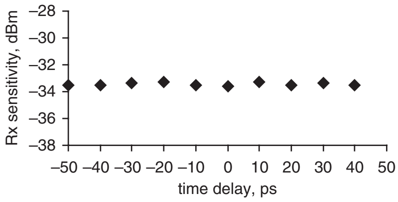

Fig. 4 *Rx sensitivities of upstream remodulated OOK signal at different delays of downstream DPSK signals*

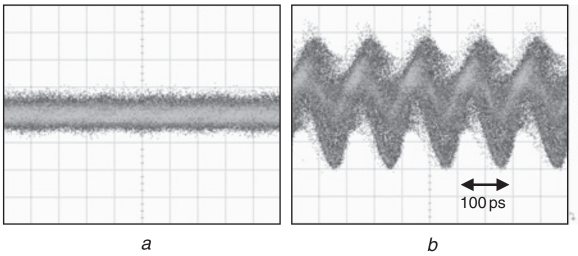

Fig. 5 *Time traces at output of RSOA and FP-LD after being injected with downstream DPSK signal*

In both cases, electrical data were disconnected
a RSOA
b FP-LD

Conclusions: We propose and demonstrate a signal remodulation scheme for high split-ratio hybrid WDM-TDM PON with 10 Gbit/s DPSK in downstream and 2.5 Gbit/s OOK in upstream using RSOA at the ONU. The phase-to-intensity and polarisation tracking issues in previous schemes can be mitigated by the proposed scheme.

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