High Extinction Ratio Phase Re-modulation for 10-Gb/s WDM-PON with Enhanced Tolerance to Rayleigh Noise

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Abstract

Downstream RZ-shaped phase modulation is used in single feeder-fiber, re-modulation-based 10-Gb/s WDM-PONs to achieve high extinction-ratio in both downstream/upstream signals. The ONU's delay-interferometer can demodulate downstream signal and simultaneously generate a source for upstream -re-modulation.

1 Introduction

Re-modulating downstream signal to generate upstream signal is an attractive solution for low-cost implementation of wavelength-division-multiplexed passive optical network (WDM-PON), as it can realize colorless optical network unit (ONU). The key issue of the re-modulation scheme is how to alleviate the upstream signal degradation caused by the downstream data when on-off keying (OOK) is used for the downstream. One straightforward approach is to reserve certain optical power in the downstream signal, by using low extinction-ratio (ER) OOK or inverse return-to-zero (IRZ) OOK as the downstream modulation format [1]. However, the downstream receiver sensitivity will be degraded by the reserved constant optical power that carries no signal. A more elegant approach has been proposed by using differential phase-shift keying (DPSK) as the downstream modulation format [2]. The phase re-modulation to generate the upstream DPSK signal can be achieved by using an XOR gate at ONU [3]. As the athermal delay-interferometer (DI) is commercially available, using DPSK in WDM-PON becomes more practical and can improve the system power budget [3]. In the schemes in [2] and [3], only one output port of the DI at ONU is used, as balance detector is expensive for access networks. The power from the other output port of the DI is wasted. In addition, the prior re-modulation schemes in [1]-[3] are vulnerable to the interferometric crosstalk induced by Rayleigh backscattering (RBS), thus dual feeder fibers are needed to avoid RBS. Extensive studies have been carried out for Rayleigh noise mitigation. However, prior reports are mainly for the carrier-distribution-based, not re-modulation-based, WDM-PON. One scheme has been proposed by using subcarrier modulation to reduce spectral overlap between the RBS and the signal. However, broadband modulator and oscillator are needed at each ONU. Another scheme by using optical phase re-modulation has been proposed [4], at the expense of the limited downstream modulation depth.

In this paper, we propose a novel phase re-modulation scheme for 10-Gb/s WDM-PON with single feeder fiber. The downstream DPSK signal is generated by a phase modulator (PM) driven by RZ-shaped differentially pre-coded data. Thus, the output from the constructive port of the DI at ONU is IRZ shaped with constant amplitude and phase in the trailing half of each bit, which can be re-modulated by the upstream DPSK signal with high ER. The output from the destructive port of the DI is RZ shaped, also with high ER, and is directly detected as the downstream signal. It has been shown in [4] that reducing the modulation depth of the downstream DPSK signal can make the upstream DPSK signal more roust to RBS noise, meanwhile the demodulated downstream signal can still maintain a high ER. Detailed analysis for the principle of RBS suppression will be given in this paper. More importantly, the downstream power budget is improved by 3.1 dB compared to that in [4], as the

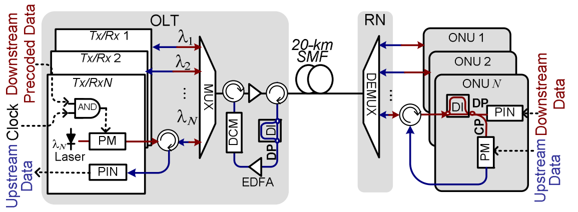

Fig. 1: Proposed phase re-modulation architecture. **DP:** destructive port, **CP:** constructive port.

upstream DPSK signal can now tolerate larger modulation depth of the downstream signal.

2 System architecture and operation principle

Fig. 1 illustrates the architecture of a WDM-PON with our proposed phase re-modulation scheme. For each downstream wavelength at the OLT, RZ-shaped electrical signal is first generated, via the AND operation between the differentially pre-coded downstream data and the clock signal, and is used to drive an optical PM to generate the downstream RZ-DPSK signal. At an ONU, the downstream RZ-DPSK signal is demodulated from the destructive port of the DI before direct detection, while light from the constructive port is fed into a PM for upstream re-modulation. At OLT, due to the periodic frequency response of DI, one common DI can be shared by all upstream channels [5].

As the phase information carried in the downstream RZ-DPSK signal only rests within the leading half of each bit, the trailing half of each bit is always with constant phase. Thus, for the destructive port output of the DI at ONU, the trailing half of each bit is always null, leading to RZ-shaped demodulated signal. Meanwhile, the trailing half of each bit in the constructive port output is always at high level and with constant phase, enabling high ER phase re-modulation by the upstream data.

The demodulated RZ-DPSK signal with reduced modulation depth (RMD-RZ-DPSK) from DI's destructive port at ONU still has a high ER, because the demodulated '0' is not degraded [4]. For the downstream RMD-RZ-DPSK signal, limited optical power shifts from central carrier tone to sidebands, due to modulation depth reduction. Thus, its RBS has narrow spectral width and can be suppressed by the notch filter-like destructive port of the DI at OLT, which is used to demodulate the upstream DPSK signal simultaneously.

Fig. 2(a) shows the measured optical spectrum (resolution bandwidth=0.06 nm) of the RBS generated by the downstream RMD-RZ-DPSK signal, whereas Fig. 2(b) shows that the RBS spectrum is substantially suppressed by the destructive port of the DI at OLT, due to its notch filter-like frequency response. On the contrary, the low-pass frequency response of the DI's constructive port cannot effectively prevent the RBS entering the upstream receiver and is not suitable for upstream DPSK signal demodulation. For comparison, the RBS spectrum at the DI's constructive port is shown in Fig. 2(c), with no obvious spectrum suppression.

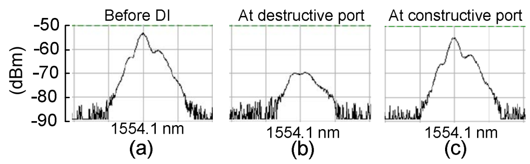

Fig. 2: Measured spectra of the RBS generated by the downstream RMD-RZ-DPSK signal. (a) before the DI at OLT, (b) at DI's destructive port, (c) at DI's constructive port.

3 Experimental demonstration

We have experimentally demonstrated the proposed re-modulation scheme based on the architecture shown in Fig. 1. At the OLT, a continuous-wave (CW) light source at 1554.1 nm was fed into a 10-Gb/s PM driven by a 10-Gb/s 2^{31}-1 pseudorandom binary sequence (PRBS) with the driving voltage of 0.33 $V\pi$. An optical band-pass filter with a 3-dB bandwidth of ~0.8nm was used to emulate one channel of a 100-GHz arrayed waveguide grating and to suppress the amplified spontaneous emission noise. After power amplification and filtering, 6-dBm RMD-DPSK signal was coupled into a 20-km SMF. At the ONU, the destructive port of a DI with a relative delay of ~100 ps was used for downstream RMD-RZ-DPSK signal detection. Signal from the constructive port (with 1.1-dB insertion loss) was fed into another PM, driven by a 10-Gb/s 2^{31}-1 PRBS with full modulation depth (FMD) as the upstream data, before being transmitted back to the OLT. At the OLT, the destructive port of another DI with ~100-ps relative delay was used for upstream FMD-DPSK signal detection and RBS noise suppression. After pre-amplification, a dispersion compensation module (DCM) for 20-km SMF, with 1.4-dB insertion loss, was used to compensate the dispersion of the upstream signals. The bit-error-rate

(BER) measurement results for downstream and upstream signals are shown in Fig. 3(a) and Fig. 3(b), respectively. The average receiver power was measured before the PIN receiver rather than before the optical pre-amplifier. For comparison, the BER curves for some reference signals are also shown in Fig. 3. In the back to back (B2B) case, the receiver sensitivity (at BER=10^{-9}) of the downstream RMD-RZ-DPSK signal is only slightly degraded compared to that of the FMD-DPSK signal, due to that the demodulated downstream RMD-RZ-DPSK signal still maintains high ER (13 dB). After transmission in 20-km SMF without dispersion compensation, the receiver sensitivity (-19.5 dBm) of the downstream RMD-RZ-DPSK signal becomes ~0.5 dB better than that of the FMD-DPSK signal. That is because the downstream RMD-RZ-DPSK signal has narrower spectrum, and is hence more robust to dispersion. Compared to reference [4], the downstream receiver sensitivity is improved from -17.9 dBm to -19.4 dBm, and the insertion loss of the destructive port of DI at ONU is reduced from 15 dB to 13.4 dB, implying 3.1-dB improvement in downstream power budget. The insets in Fig. 3(a) show the wide-open eye diagrams of the downstream RMD-RZ-DPSK signal in both B2B and transmission cases. The eye diagram of the IRZ-shaped constructive port output is also shown in the inset of Fig. 3(a). The amplitude and phase are nearly constant in the area surrounded by the dashed line and thus can be used for upstream phase re-modulation.

Compared with using CW light as the upstream source, ~1-dB power penalty (at BER=10^{-9}) is observed for the upstream signal using the proposed re-modulation scheme, as shown in Fig. 3(b). Compared with the case using dual feeder fiber, the residual RBS noise induces ~1.5-dB power penalty for the upstream signal after 20-km transmission. The ER of the upstream signal was measured to be ~9 dB. The insets in Fig. 3(b) show the wide-open eye diagrams of the upstream DPSK signal. With a shared preamplifier at OLT, error-free transmission is obtained for the upstream signal.

4 Summary

We have proposed and experimentally demonstrated a novel wavelength re-modulation scheme for 10-Gb/s

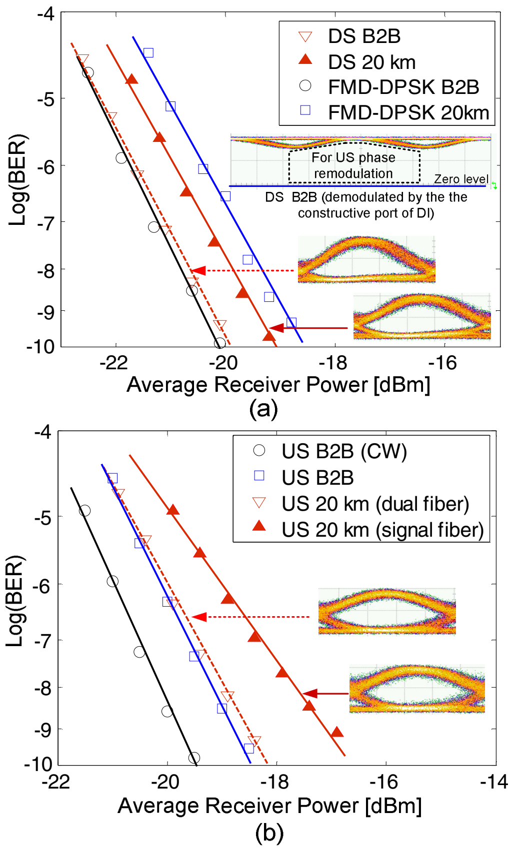

Fig. 3: BER measurement results of (a) DS signals, (b) DS signals. Time scale of insets: 20ps/div. **DS:** downstream, **US:** upstream.

WDM-PON using single feeder fiber. Downstream RZ-shaped phase modulation enables larger downstream modulation depth and improves downstream power budget by 3.1 dB. The un-modulated part of the downstream RMD-RZ-DPSK signal will not degrade downstream receiver sensitivity, compared to the schemes using downstream low-ER OOK and IRZ-OOK. The DI at ONU used for downstream signal demodulation can simultaneously extract the un-modulated part as the source for upstream re-modulation. Thus the un-modulated part will not enter downstream receiver, avoiding receiver sensitivity degradation. This project is supported in part by HKSAR RGC GRF 410908.

5 References

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