Optical Phase Remodulation for 10-Gb/s WDM-PON with Enhanced Tolerance to Rayleigh Noise

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Abstract: A novel phase remodulation scheme for 10-Gb/s WDM-PON is proposed and demonstrated. Downstream DPSK signal with a reduced modulation depth facilitates upstream phase remodulation and Rayleigh noise suppression. High extinction-ratio is attained in downstream/upstream demodulation.

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1. Introduction

The wavelength-division-multiplexed passive optical network (WDM-PON) is a promising technology for the next-generation access networks. Remodulating downstream signal to generate upstream signal is an attractive solution for low-cost implementation of WDM-PON [1], as it halves the required wavelengths and eliminates the need of wavelength-specific transmitters and wavelength management at the optical network unit (ONU). The intrinsic Rayleigh backscattering (RBS) induces severe interferometric crosstalk if single feeder fiber is used in the conventional remodulation schemes, due to the reuse of the same wavelength. To mitigate the interferometric crosstalk noise, in [2], the downstream signal was modulated using frequency-shift keying to reduce light coherence, thus reducing the RBS effect on upstream channels. However, the residual crosstalk noise still induced a penalty of 5 dB at 1-Gb/s. Another scheme utilized downstream 10-Gb/s differential phase-shift keying (DPSK) and upstream 2.5-Gb/s subcarrier modulation to reduce spectral overlap between the reflections and the signals [3]. As a broadband modulator and oscillator, with a bandwidth of several times larger than the signal bit rate, are needed at each ONU, it is difficult to realize 10-Gb/s symmetric bit-rate that is highly desirable for future-proof PON systems.

In this paper, we propose a novel remodulation scheme for 10-Gb/s WDM-PON with single feeder fiber by using downstream DPSK with reduced modulation depth (RMD) and upstream DPSK with full modulation depth (FMD). Interestingly, the demodulated RMD-DPSK signal from the destructive port of the delay-interferometer (DI) at ONU still maintains a high extinction-ratio (ER), whereas the signal from the constructive port has a very low ER and can be used as the source for upstream phase remodulation. Thanks to the reduced spectral width of the RMD-DPSK, the RBS towards the optical line terminal (OLT) also has narrow spectral width and can be suppressed by the notch filter-like destructive port of the DI at OLT, which is simultaneously used to demodulate the upstream DPSK signal. Compared to prior remodulation schemes, no additional device is required to suppress RBS noise, and the ONU structure is also simplified, as a power splitter is eliminated and the DI at ONU is used for both downstream signal demodulation and the separation of the downstream/upstream signals.

2. Principle and system architecture

Fig. 1(a) illustrates the proposed remodulation scheme for WDM-PON using downstream RMD-DPSK and upstream FMD-DPSK. For each downstream wavelength at the OLT, differentially precoded data is used to drive an optical phase modulator (PM) with a low driving voltage to generate the downstream RMD-DPSK signal. All the downstream wavelengths at the OLT are multiplexed by an arrayed waveguide grating (AWG). The multiplexed

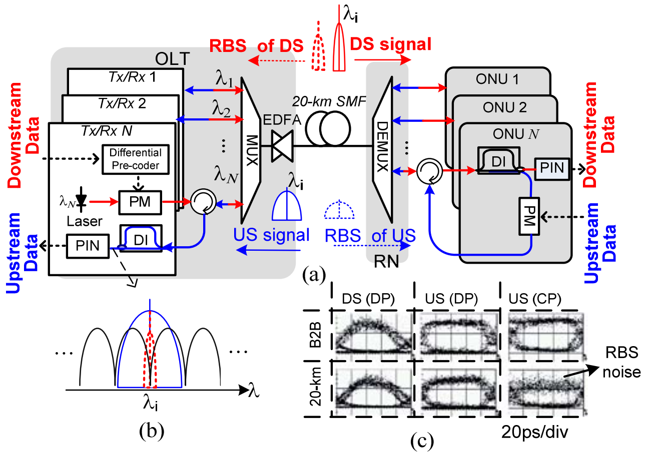

Fig. 1: (a) Proposed single-fiber re-modulation architecture. (b) schematic illustration of RBS noise suppression. (c) Eye diagrams of the DS RMD-DPSK and US FMD-DPSK signals in B2B and transmission cases. **B2B:** back-to-back, **DS:** downstream, **US:** upstream, **DP:** destructive port of the DI, **CP:** constructive port.

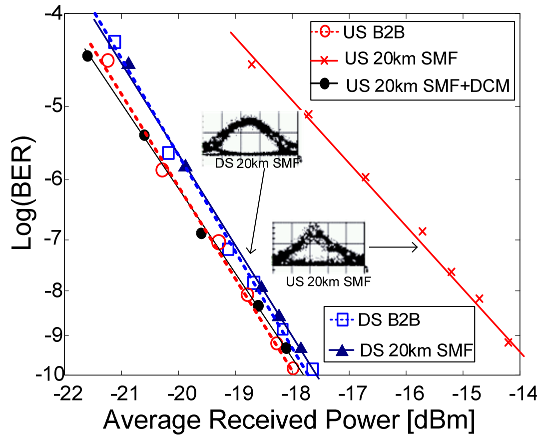

Fig. 2: BER measurements of both DS RMD-DPSK and US FMD-DPSK signals. Time scale of insets: 20ps/div. **DS:** downstream, **US:** upstream.

signals are first amplified and then fed into a 20-km SMF. After transmission, the downstream signal from the OLT is wavelength routed by another AWG at the remote node (RN) toward different ONUs. At an ONU, the downstream RMD-DPSK signal is demodulated from the destructive port of the DI before direct detection, while the light from the constructive port is fed into a PM for upstream data remodulation.

Intuitively, the ER of the demodulated downstream RMD-DPSK signal should be degraded due to the RMD. Actually, the ER degradation depends on which port of the DI is used for demodulation. For the destructive port, the demodulated '0' is the same as that in the case of FMD, as '0' denotes that the adjacent bits have the same phase, disregarding the specific phase values of the adjacent bits. Thus, the ER of the demodulated RMD-DPSK signal from the destructive port is independent of the phase modulation depth and is always infinite, theoretically. In practice, due to additional noise and device imperfection, the ER cannot reach infinity. However it can still maintain a high value for a large range of phase modulation depth. On the contrary, the ER of the output signal from the constructive port is substantially reduced, which greatly facilitates upstream phase remodulation. One issue is that the insertion loss is larger if the destructive port is used for RMD-DPSK demodulation, due to the reduced '1' level. The reduced optical power actually appears at the constructive port, from the principle of conservation of energy. Here we propose to use the constructive port output as the source for phase remodulation, thus its power increase by RMD will benefit the upstream power budget. The narrow spectrum from the constructive port is markedly broadened after phase remodulation by the upstream data with FMD. Thus, the upstream FMD-DPSK can be properly demodulated by the DI at OLT, with relatively low filtering loss, as shown in Fig. 1(b). On the contrary, as the spectrum of RBS towards the OLT is as narrow as the downstream RMD-DPSK signal, the RBS noise is considerably rejected by the destructive port of the DI at OLT due to its notch filter-like wavelength response. As the upstream signal is much smaller in power than the downstream signal, the RBS towards the ONU has a low power and no obvious effect on the downstream signal.

3. Experimental demonstration

We have experimentally demonstrated the proposed remodulation scheme based on the setup shown in Fig. 1(a). At the OLT, a continuous-wave light source at 1549.2 nm was fed into a PM driven by a 10-Gb/s 2^{31}-1 pseudorandom binary sequence (PRBS) with the driving voltage of 0.22 $V\pi$. An optical bandpass filter with a 3-dB bandwidth of ~0.8nm and an insertion loss of 1.5 dB was used to emulate one channel of a 100-GHz AWG 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. It was observed the input power to the SMF should be lower than 7.5 dBm to avoid signal degradation caused by stimulated Brillouin scattering. At the ONU, the destructive port of a DI with a relative delay of ~100 ps was used for downstream RMD-DPSK signal detection. Signal from the constructive port (with 1.4-dB insertion loss) was fed into another PM, driven by a 10-Gb/s 2^{31}-1 PRBS with 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. To investigate the enhanced RBS tolerance, first the effect from dispersion was isolated, by using a dispersion compensation module (DCM) to fully compensate the dispersion in the 20-km SMF. Fig. 1(c) depicts the eye diagrams of the detected downstream RMD-DPSK and upstream FMD-DPSK signals in both back-to-back (B2B) and transmission cases. Although the driving voltage of the PM was only 0.22 $V\pi$ and the measured insertion loss of the DI during demodulation was 15 dB, the eye of the demodulated DPSK signal from the destructive port of the DI was still wide-open, with a measured ER of ~9 dB. The eye of the upstream FMD-DPSK signal demodulated by the destructive port of the DI at OLT was also clearly open. For comparison, the eye of the upstream signal demodulated by the constructive port, which was severely degraded by the RBS, was also shown. We then removed the DCM to investigate the proposed scheme without dispersion compensation. The bit-error-rate (BER) measurement results for both downstream and upstream signals were shown in Fig. 2. After transmission in 20-km SMF without dispersion compensation, the receiver sensitivity at BER=10^{-9} for the downstream RMD-DPSK signal was -17.9 dBm, while that for the upstream FMD-DPSK signal was -14.2 dBm. The loss caused by the 20-km SMF was around 4 dB. Considering the 3-dB insertion loss of an AWG and 0.5-dB insertion loss of a circulator, the downstream RMD-DPSK signal still has 1.4-dB system margin, despite the 15-dB insertion loss of destructive port of the DI.

After transmission in 20-km SMF with DCM, less than 0.3-dB power penalty was observed for both downstream RMD-DPSK and upstream FMD-DPSK signals, demonstrating the robustness of the proposed scheme to the RBS noise. Without DCM after transmission in 20-km SMF, ~4-dB power penalty, mainly due to dispersion, was observed for the upstream FMD-DPSK signal. Negligible power penalty was observed for the downstream RMD-DPSK signal, thanks to the its reduced spectral width.

4. Conclusions

We have proposed and experimentally demonstrated a novel remodulation scheme for WDM-PON with single feeder fiber by using downstream RMD-DPSK and upstream FMD-DPSK. Error-free operation of both down- and up-stream signals, at 10-Gb/s, is achieved after the transmission of 20-km SMF. This project is supported in part by HKSAR RGC GRF 411007.

5. References

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