

WDM PON using 10-Gb/s DPSK downstream and re-modulated 10-Gb/s OOK upstream based on SOA

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Abstract A signal remodulation scheme of 10-Gb/s differential phase-shift keying (DPSK) downstream and 10-Gb/s on-off keying (OOK) upstream using a semiconductor optical amplifier (SOA) and a Mach-Zehnder intensity modulator (MZ-IM) at the optical networking unit (ONU) side for wavelength division multiplexed passive optical network (WDM PON) is proposed. Simulation results indicate that error-free operation can be achieved in a 20-km transmission, and the receiver sensitivity of return-to-zero differential phase-shift keying (RZ-DPSK) is higher than nonreturn-to-zero differential phase-shift keying (NRZ-DPSK) in the proposed scheme.

Keywords wavelength division multiplexed passive optical network (WDM PON), differential phase-shift keying (DPSK), semiconductor optical amplifier (SOA)

1 Introduction

The wavelength division multiplexed passive optical network (WDM PON) is considered as a promising candidate to provide broadband access for the next generation networks. Reducing the costs of WDM PON will be the key challenge for their deployment. For the WDM PON architecture, using a centralized light source at the central office (CO) is emerging as a cost-effective deployment. With this architecture, the downstream optical signals can be reused as the light source for the upstream carrier at the optical networking unit (ONU).

Recently, several proposals for the colorless ONUs have been reported and studied, such as using spectrum-sliced light-emitting diodes [1], injection-locked Fabry-Perot laser diodes (FP-LDs) [2], semiconductor optical amplifier (SOA) [3], and reflective semiconductor optical amplifier

(RSOA) [4]. However, these networks have been implemented to operate at moderate speed in the range of 0.155–5 Gb/s due to the limited bandwidths of the directly modulated colorless light sources [5]. A 10-Gb/s operation of RSOA for WDM PON using electronic equalization and forward error correction (FEC) techniques is reported [6]. However, it will increase the complexity of the ONU by using these equalizers.

The SOA is a promising candidate for metro and access network for its compact size, wide amplification bandwidth, integration with other devices, and potential low cost. However, in linear applications, gain saturation and cross-gain modulation (XGM) in SOAs can degrade the transmission performance when on-off keying (OOK) modulation is employed [7]. Constant-intensity modulation format such as differential phase-shift keying (DPSK) is, in principle, immune to XGM-induced crosstalk in SOAs. Recent reported results show that DPSK modulation format can realize long-distance and high-spectral efficient signal transmission by using SOA in-line application [8].

In this paper, we propose a signal remodulation scheme of downstream DPSK and upstream OOK both operating at 10 Gb/s using an SOA and an external modulator. Nonreturn-to-zero differential phase-shift keying (NRZ-DPSK) and return-to-zero differential phase-shift keying (RZ-DPSK) are investigated and compared as the downstream modulation format. The downstream optical signals are amplified by an SOA and then re-modulated by a Mach-Zehnder intensity modulator (MZ-IM) before sending back to the CO. Thus, this scheme does not require any light source at the ONU and can provide sufficient power budgets for the upstream signals.

2 Principles

The proposed WDM PON architecture is shown in Fig. 1.

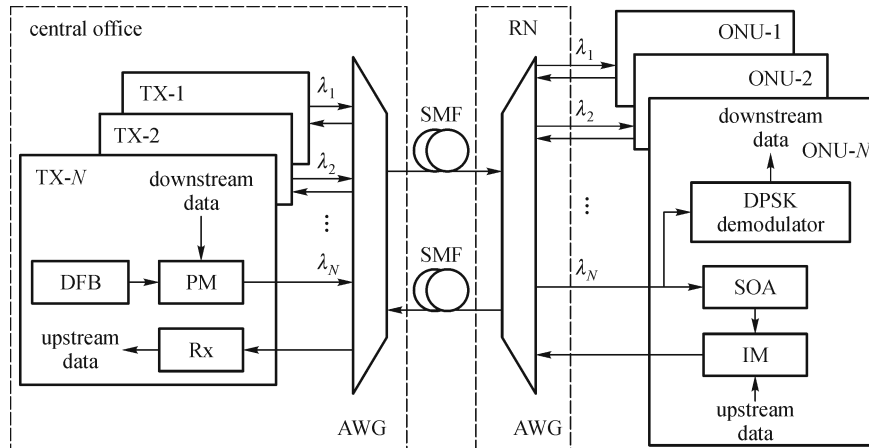


Fig. 1 Proposed WDM PON system

A CO consists of a distributed feedback laser diode (DFB-LD) array which offers the wavelength from λ_1 to λ_N for downlink. The differentially precoded downstream data are modulated onto a specific wavelength channel through a phase modulator (PM). Then the optical DPSK signal is transmitted from the CO to the ONUs through an arrayed waveguide grating (AWG) at the remote node (RN). At the ONU side, part of the received optical power is fed into a DPSK demodulator to recover the downstream signals while the rest of the downstream optical signals are launched into the SOA. Then the amplified optical signal is directly modulated by the intensity modulator (IM) and sent back to the CO by a different single mode fiber (SMF) to reduce Rayleigh backscattering. As the DPSK optical pulse is present in every bit slot, the upstream data can be directly modulated by the OOK modulator.

3 Simulation model setup

To discuss the performance of the proposed WDM PON system, we establish a model for simulation using OptiSystem as shown in Fig. 2. Continuous-wave (CW) light from a DFB laser, operated at 1550 nm, is modulated by a Mach-Zehnder phase modulator (MZ-PM), which is driven by a 10-Gb/s differentially precoded nonreturn-to-zero (NRZ) pseudo random binary sequence (PRBS) with a length of $2^{10}-1$. The Mach-Zehnder modulator (MZM), operated as a DPSK modulator, is driven in push-pull configuration to minimize chirp. A sinusoidally driven modulator (pulse carver) is used to carve pulses out of the phase-modulated signal, thus generating RZ-DPSK. The variable optical attenuator (VOA) is used to measure the receiver sensitivity of the output signal. Then the downstream signal is fed into a span of 20-km SMF via a pair of AWG (Gaussian shaped, 3-dB width of 50 GHz). Dual-feeder fiber architecture is used to reduce Rayleigh backscattering at the CO receiver in the network.

At the ONU side, a portion of the downstream received optical power is tapped off by a 50/50 power splitter. The constant intensity downstream DPSK signal is demodulated by a 1-bit delayed interferometer (DI). This signal is differentially detected by balanced photodiodes. The rest of the downstream optical signal is amplified by an SOA and then re-modulated by an MZ-IM, which is driven by another 10-Gb/s NRZ PRBS with a length of $2^{10}-1$. Then the generated upstream signal is transmitted back to the CO, via another piece of 20-km SMF.

4 Results and discussion

Based on the proposed simulation model in Fig. 2, the eye diagram and receiver sensitivity for NRZ-DPSK and RZ-DPSK at 10 Gb/s for both directions are compared. Figures 3 and 4 show the measured eye diagrams of the downstream signals and upstream signals at back-to-back and after 20-km transmission.

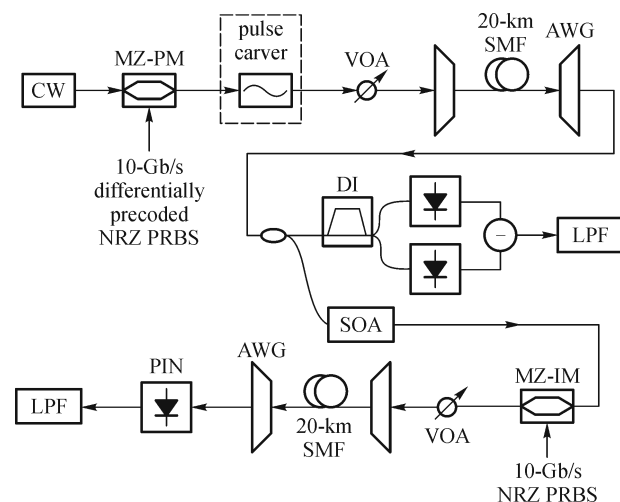


Fig. 2 Simulation model setup of proposed WDM PON link

The eye diagrams of downstream NRZ-DPSK signals after balanced detection are shown in Figs. 3(a) and 3(b). It is clear that the eye-opening of the 20-km transmission is very close to the back-to-back transmission. Thus, the power penalty of downstream NRZ-DPSK will be low. The same results can be seen in RZ-DPSK transmission. And since the downstream DPSK signals have high optical signal-to-noise ratio (OSNR) after 20-km transmission, they will be good candidates as the input optical signals for the SOA.

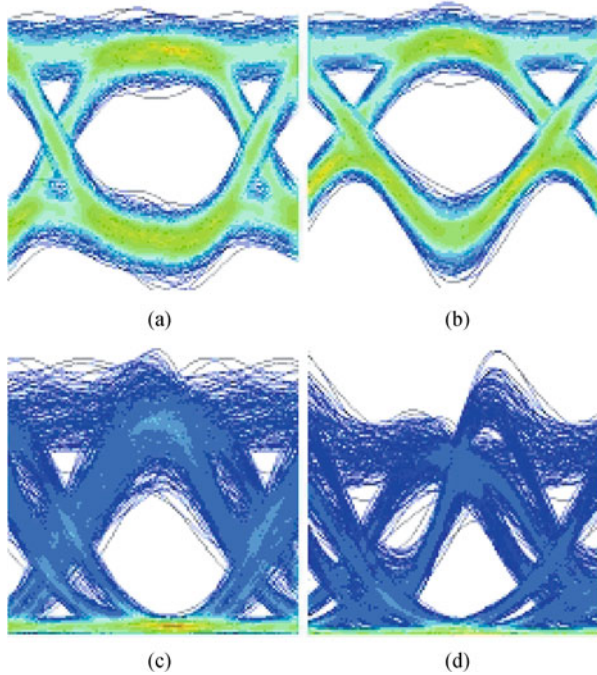


Fig. 3 Eye diagram of downstream NRZ-DPSK and upstream OOK. (a) NRZ-DPSK at back-to-back; (b) NRZ-DPSK after 20-km transmission; (c) re-modulated OOK at back-to-back; (d) re-modulated OOK after 20-km transmission

For the upstream signals, it can be seen that the noise on zero line of OOK is small. As the MZ-IM is put after the SOA, the noise on zero decreases after OOK modulation. But if the downstream DPSK is first modulated by the MZ-IM and then fed into the SOA, the eye diagram of the upstream OOK signal is almost closed as the noise on zero is amplified. We also note that the ones suffer large noise from the SOA. This is due to the fact that the optical power from the downstream signal is fluctuant after 20-km transmission. Then the optical signal with different power level will experience different power gain after the SOA, so the noise of ones is also amplified. In the RZ-DPSK modulation scheme, although an NRZ-OOK modulator is employed as an upstream modulator, the re-modulated signals perform an RZ-OOK pattern. Since the MZ-IM does not change the shape of the input optical pulse, RZ optical signals for upstream transmission can be generated. By comparing the eye diagram of upstream OOK

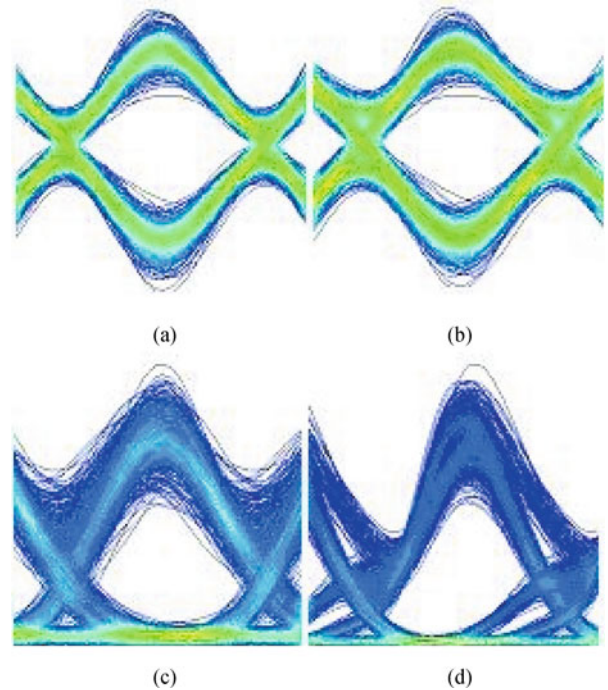


Fig. 4 Eye diagram of downstream RZ-DPSK and upstream OOK. (a) RZ-DPSK at back-to-back; (b) RZ-DPSK after 20-km transmission; (c) re-modulated OOK at back-to-back; (d) re-modulated OOK after 20-km transmission

transmission after 20 km between NRZ-DPSK and RZ-DPSK, we can see that the RZ-DPSK performs better than NRZ-DPSK. This is because that in the NRZ modulation format, the ones suffer from more noise after amplification.

Figures 5 and 6 show the receiver sensitivity of the downstream and upstream signals at back-to-back and after 20-km transmission. From the two figures, we can see that both the downstream DPSK and upstream OOK power

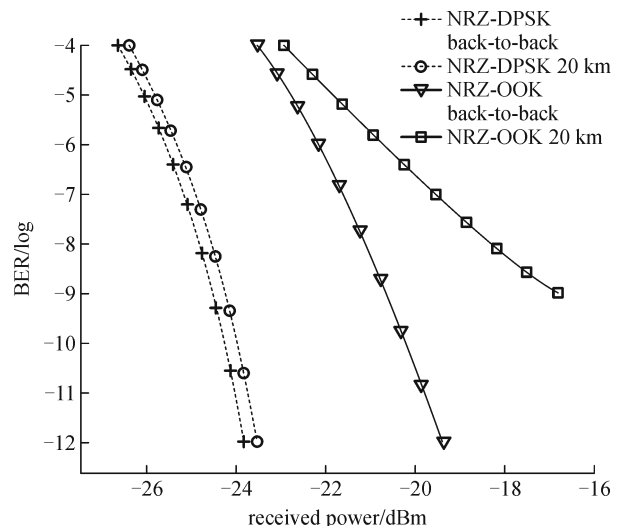


Fig. 5 BER measurements of downstream NRZ-DPSK and upstream OOK

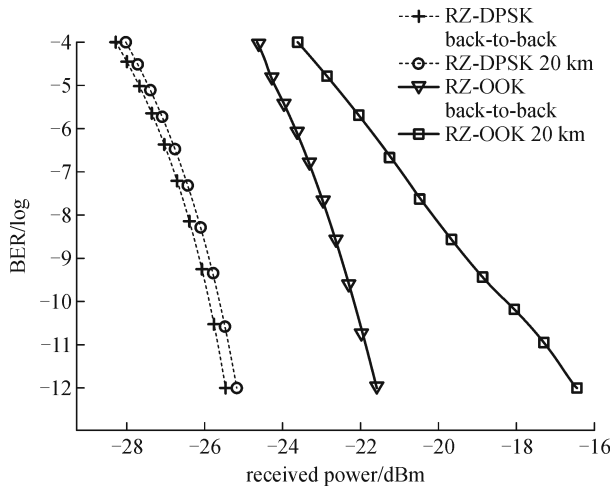


Fig. 6 BER measurements of downstream RZ-DPSK and upstream OOK

penalties are almost the same for NRZ-DPSK and RZ-DPSK schemes. The downstream DPSK signals at back-to-back have the best receiver sensitivity, while the upstream OOK signals have the worst performance after 20-km transmission. By comparing the bit error rate (BER) of back-to-back to 20-km transmission, the maximum power penalty was about 0.5 dB at the BER of 10^{-9} for downstream DPSK signals. For the upstream OOK signal, about 3-dB power penalty was measured after 20-km transmission at the BER of 10^{-9} . In comparison, the receiver sensitivity of RZ-DPSK is found to be 1.5 dB better than that of NRZ-DPSK. This is because, unlike NRZ-DPSK modulation, RZ-DPSK has a data-independent intensity profile and completely removes the pattern effect.

5 Conclusions

In conclusion, we have proposed and demonstrated a centralized lightwave scheme for WDM PON using 10-Gb/s DSPK in downstream and 10-Gb/s OOK in upstream with an SOA and an MZ-IM at the ONU. The downstream optical signal is amplified and re-modulated, then sent to the ONU as a light source. The power penalty for the 10-

Gb/s downstream signals after 20-km transmission is 0.5 dB at a BER of 10^{-9} , while the power penalty is 3 dB at a BER of 10^{-9} for upstream transmission. NRZ-DPSK and RZ-DPSK for downstream modulation are investigated and compared; the results show that the receiver sensitivity of RZ-DPSK is 1.5 dB better than that of NRZ-DPSK.

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