A cost-effective structure of a centralized-light-source WDM-PON utilizing inverse-duobinary-RZ downstream and DPSK upstream*

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In this paper, we propose a new structure of a centralized-light-source wavelength division multiplexed passive optical network (WDM-PON) utilizing inverse-duobinary-return-to-zero (inverse-duobinary-RZ) downstream and DPSK upstream. It reuses downstream light for the upstream modulation, which retrenches lasers assembled at each optical network unit (ONU), and ultimately cuts down the cost of ONUs a great deal. Meanwhile, a 50-km-reach WDM-PON experiment with 10-Gb/s inverse-duobinary-RZ downstream and 6-Gb/s DPSK upstream is demonstrated here. It is revealed to be a novel cost-effective alternative for the next generation access network.

Keywords: inverse-duobinary-return-to-zero, wavelength division multiplexed passive optical network (WDM-PON), DPSK

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1. Introduction

Driven by the exponential increase of multimedia services and data traffic, tremendous demands for bandwidth has become a severe challenge for future network construction. As a promising solution for the next-generation access network, wavelength division multiplexed passive optical networks WDM-PONs) have been proposed in recent years. However, with the practical deployment in the access network, every optical network unit (ONU) requires an independent laser for upstream modulation and to avoid aliasing from neighboring channels. Cost saving and wavelength assignments are the main challenges in a WDM-PON.[1–6]

One feasible approach is to employ centralized light sources (CLS) at the optical line terminal (OLT) and directly reuse the downstream light as the upstream carrier at the ONU. Moreover, at the ONU side, simple direct detection is utilized to complete demodulation, and no laser is needed for upstream modulation, which largely cuts down cost of ONUs. In the realization of a CLS WDM-PON, inverse-return-to-zero (inverse-RZ) is the approachable option for the downstream signal format, since it carries power in both '1'and '0' bits, then the reversed optical power for uplink modulation at ONU side is higher compared with a conventional RZ .

In this paper, we have proposed a novel structure of a centralized-light-source WDM-PON utilizing inverse-duobinary-RZ downstream and DPSK upstream, as a novel cost-effective alternative for the next generation access network.

Conventional inverse-RZ exhibits lower dispersion tolerance which refines the uncompensated transmission distance. By combining inverse-RZ and duobinary coding together, inverse-duobinary-RZ performs better than conventional inverse-RZ in resistance to CD and suppression for nonlinearity.[7–10] It proves to be an advantageous solution for downstream transmission in contrast. Meanwhile, the optical power reservation of inverse-duobinary-RZ is outstandingly higher than conventional RZ, which is relatively economic with applying CLS technology.[11]

In recent proposed structures, the reflective semiconductor optical amplifier (RSOA) and the reflective semiconductor electro-absorption modulator (REAM) employed are more practical.[12–14] However, in our proposed structure, for downlink, the bias point should be kept at the negative slope part of the Mach–Zehnder modulator (MZM) transmission curve to achieve a completely opposite power property with conventional RZ. For uplink, we adopt phase modulation to avoid possible Rayleigh backscattering induced performance degradation. RSOA and REAM may be not the most appropriate option. The scheme of applying different modulation types for bi-direactional transmission in WDM-PON or PON have been proposed in Ref. [15]– [19]. Additionally, with employing phase modulator for upstream transmission, no extra bias control circuits are needed at the ONU side to monitor bias voltage drifting, and phase modulator may be more convenient in installation.

We also experimentally confirmed its feasibility and validity through a 50-km-reach WDM-PON experiment with 10-Gb/s inverse-duobinary-RZ downstream and 6-Gb/s DPSK upstream. The upstream bit error ratio (BER) achieves a min-

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imum below 10^{-9} when the received optical power is controlled above –25.8 dBm.

2. Proposed structure of CLS WDM-PON

Figure 1 illustrates the CLS WDM-PON architecture utilizing inverse-duobinary-RZ downstream and DPSK upstream. At the OLT side, each transmitter at the OLT generates its downstream inverse-duobinary-RZ signal and receives its upstream re-modulated signals from its respective wavelength. All downstream modulated wavelengths are multiplexed, via an array waveguide grating (AWG).

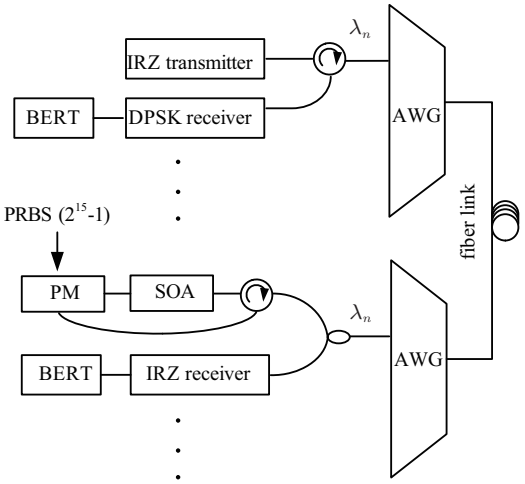


Fig. 1. Proposed structure of CLS WDM-PON. AWG: array waveguide grating; SOA: semiconductor optical amplifier; BERT: bit error rate tester; PM: phase modualtor.

For each ONU, the received optical signal is split into two branches: one is directly detected and demodulated, and then sent to bit-error-rate tester (BERT) for BER measurement; the other is reused as upstream optical carrier, first amplified through a semiconductor optical amplifier (SOA) to meet the power requirement for the upstream light source, and then sent to the corresponding channels. The pseudo random binary sequence (PRBS) of $2^{15}-1$ is amplified and fed into the PM to realize the upstream DPSK modulation.

3. Generation of inverse-duobinary-RZ and the experimental setup

Schemes for generation of inverse-RZ have been proposed in recent years, however, there are still some drawbacks included in these solutions: the duty cycle cannot be simply regulated, and phase varies with RZ modulation.[20–24] Here we adopt a new method to cover the generation of inverse-RZ. It is to be noted that the duty cycle of inverse-RZ can be defined as the fraction of mark level share during the bit interval, usually expressed as a percentage.

As shown in Fig. 2, the generated NRZ code is differential encoded, and delayed by a certain duration, which is revealed to be 1/6 bit. Then, subtraction operation takes place between the original differential sequence a and delayed sequence b, and the subtracting results (a–b) will be the generated duobinary-RZ signal, which the positive and negative mark levels will alternatively arranged. We can clearly see that the duty cycle of duobinary RZ directly relies on the delayed bit duration. The delay-subtraction manipulation can be realized through up-sample and certain samples delayed in pulse pattern generator (PPG), which is simplified to be logical operations in the RF transmitter. However, since there is always small remaining power for '0' bit in NRZ, the amplitude of generated duobinary-RZ signal will inevitably deteriorate to a small extent, which has impact on the extinct ratio (ER). The generated duobinary-RZ signal is then fed into MZM, and biased at the maximum transmission point. Thus, space level corresponds to high optical power, and mark level corresponds to low power, which forms the inverse-duobinary-RZ signal.

The experimental setup of the proposed scheme is depicted in Fig. 3. At the OLT side, the DFB laser is located at 1550.24 nm to provide optical source. The electrical duobinary-RZ signal formed in PPG as described above, is first sent into the MZM to realize inverse duobinary RZ, and then propagates along 50-km standard single-mode fiber (SSMF). The net data speed of inverse RZ reaches up to 10 Gb/s.

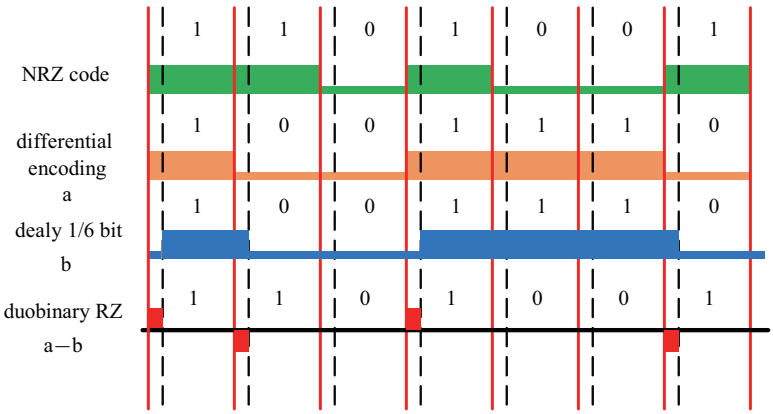


Fig. 2. (color online) Coding schedule of duobinary RZ.

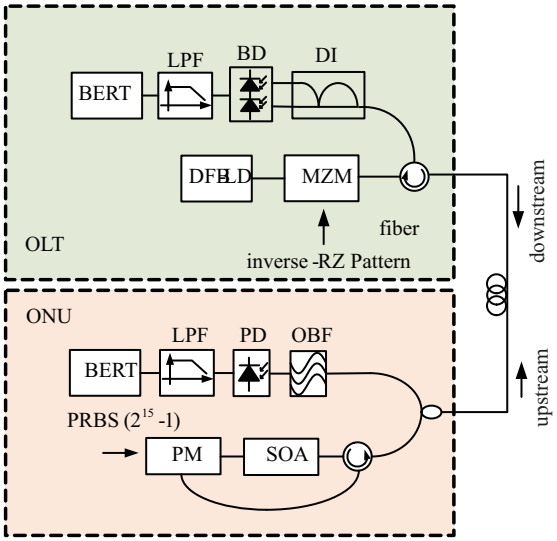


Fig. 3. (color online) Experimental setup for the proposed bidirectional transmission system.

At the ONU side, the downstream light is first split by the optical splitter. One branch is sent for BER measurements, which is completely identical to conventional direct detection, and the other branch is amplified through a SOA to meet the power requirement for upstream optical source. The upstream data stream with PRBS 15 is fed into a PM to cover the DPSK modulation. The data speed of upstream PRBS is set at 6 Gb/s.

Then, the upstream DPSK signal is transmitted along fiber links, and received at OLT side. In the demodulation for upstream DPSK signal, an optical delay interferometer (DI) is employed with one-bit delay, and a balance detector follows to correspond to constructive and destructive ports of DI.[25] Then, a 6-GHz low-pass filter (LPF) for signal shaping is finally sent to the BERT for BER measurements.

4. Experiment results and analysis

Figure 4 depicts the curve of the downstream BER as a function of the received optical power for back-to-back and 50-km transmission with the launch power of –2 dBm. The required received power for 10^{-3} BER is –30.7 dBm and –30 dBm respectively for back-to-back (B-T-B) and 50-km in 33% duty cycle case. The inset eye diagrams are taken with received power at –30.5 and –25.5 dBm in back-to-back case with a BER of 10^{-3} and 5×10^{-12}, and at –28 dBm in 50-km case with a BER of 3×10^{-6}. Compared with back-to-back operation, the transmission over 50 km by standard SMF shows a power penalty of 1.0 dB at 3×10^{-7} BER, and 1.5 dB at 5×10^{-12} BER.

Figure 5 depicted the downstream BER against received optical power for 50-km transmission with duty cycle of inverse-RZ set at 33%, 50%, and 67%. The performance trend of the downstream transmission keeps consistent with different duty cycles. For inverse RZ, a larger duty cycle leads to lower BER at the same received power, and the slopes of three fitting curves show small deviations. For the 50% case, =the power penalty is 1.5 dB more than that in 67% case at 10^{-12} BER, and a power penalty of 4.0 dB is clearly observed between 50% and 33% cases at 10^{-12} BER.

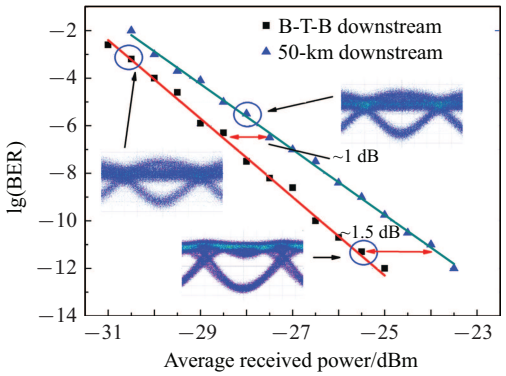


Fig. 4. (color online) BER versus received optical power for downstream using IRZ in B-T-B and 50-km cases.

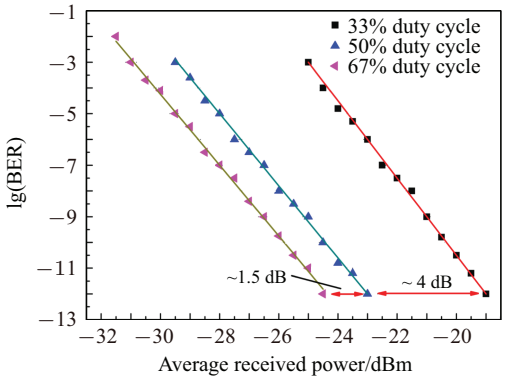


Fig. 5. (color online) BER versus the received optical power for 50-km downstream using IRZ with 33%, 50%, and 67% duty cycle.

For upstream transmission, the BER as a function of the received optical power for back-to-back and 50-km transmission in case of 33% duty cycle is demonstrated in Fig. 6. The required received powers for 10^{-3} and 10^{-9} BER are respectively –34 and –28 dBm for 50-km transmission. The inset eye diagrams are taken with received power at –34, –31.5, and –29.5 dBm in 50-km case with a BER of 10^{-3}, 4×10^{-7}, and 10^{-9}. A 2-dB power penalty is achieved in back-to-back case and 50-km case at 10^{-11} BER.

Figure 7 shows the upstream BER as a function of the received optical power for 50-km transmission with duty cycle of inverse-RZ set at 33%, 50%, and 67%. Similar to downstream transmission, the slope of three fitting curves show small deviations, and the measured slope appears gentler in contrast. However, it shows an opposite trend compared with downstream transmission, and larger duty cycle will lead to higher BER at the same received power. For the 50% case, the power penalty is 0.9 dB more than that in 33% case at

2.5×10^{-6} BER, and a 1.5-dB power penalty is clearly observed between 50% and 67% cases at 3×10^{-9} BER.

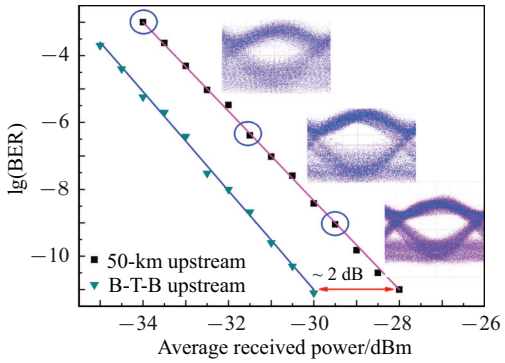


Fig. 6. (color online) BER as a function of the received optical power with 33% duty cycle for upstream in B-T-B and 50-km cases.

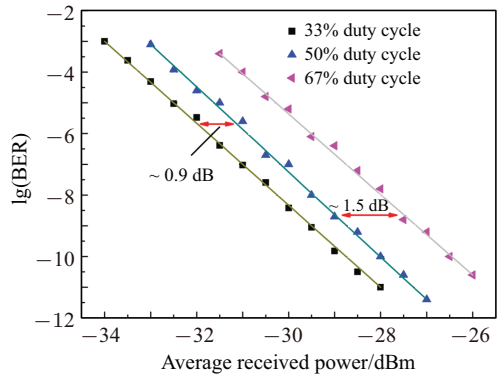


Fig. 7. (color online) BER versus the received optical power for upstream with 33%, 50%, and 67% duty cycle.

5. Conclusion

In this paper, we have proposed a new structure of a centralized-light-source WDM-PON utilizing inverse-duobinary-RZ downstream and DPSK upstream. It has been proved to be a novel cost-effective alternative for the next generation access network. We have implemented a 50-km-reach WDM-PON experiment with 10-Gb/s inverse-duobinary-RZ downstream and 6-Gb/s DPSK upstream. The upstream BER is below 10^{-9} when the received optical power is controlled above –25.8 dBm.

References

[1] Kazovsky L G, Shaw W T and Gutierrez D 2007 *J. Lightwave Technol.* **25** 3428
[2] Banerjee A, Park Y, Clarke F, Song H, Yang S, Kramer G, Kim K and Mukherjee B 2005 *J. Opt. Netw.* **4** 737
[3] Chung Y C, Jung D K, Youn C J and Woo H G 2000 *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference*, March 7, 2000 Baltimore, USA, p. WJ6-1
[4] Woodward S L, Iannone P P, Reichmann K C and Frigo N J 1998 *Photonic. Tech. Lett.* **10** 1337
[5] Healey P, Townsend P, Ford C, Johnston L, Townley P, Lealman I, Rivers L, Perrin S and Moore R 2001 *Electron. Lett.* **37** 1181
[6] Kani J I, Bourgart F, Cui A, Rafel A, Campbell M, Davey R and Rodrigues S 2009 *IEEE Commun. Mag.* **47** 43
[7] Liu Z X, Xu J, Qiu Y and Chan C K 2010 *The 36th European Conference and Exhibition*, September 19, 2010 Torino, Italy, p. 1
[8] Agrawal G P 1995 *Nonlinear Fiber Optics* (2nd edn.) (SanDiego, CA: Academic) p. 15
[9] Du L and Lowery A 2009 *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference*, March 22, 2009 San Diego, USA, p. OTuO1
[10] Yong Z, Jin K and Zhang Z 1994 *Chin. Phys. Lett.* **11** 145
[11] Huang W 2005 *Photon. Technol. Lett.* **15** 1476
[12] Huang Y S, Chang C H, Lin W Y, Ho W J and Lu H H 2010 *Optical Electronics and Communications Conference*, July 15, 2010 Sapporo, Japan, p. 30
[13] Huang Y S, Lin H S, Liang Y Y, Tsai N Y and Lai P C 2010 *Photonics Global Conference*, December 14, 2010 Orchard, Singapore, p. 14
[14] Garreau A, Decobert J and Kazmierski C 2006 *Indium Phosphide and Related Materials Conference Proceedings*, May 8, 2006 New York, USA, p. 168
[15] Wang C H, Shih F Y, Chow C W, Yeh C H and Chi S 2009 *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference*, March 22, 2009 San Diego, USA, p. JWA73
[16] Hung W, Chan C K, Chen L K and Tong F 2003 *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference*, March 25, 2003 Atlanta, USA, p. TuR2
[17] Chowdhury A, Chien H C, Huang M F, Hsueh Y T and Chang G K 2008 *The 21st Annual Meeting of IEEE*, November 9, 2008 Newport Beach, USA, p. 673
[18] Huang M F, Qian D Y and Chen L 2008 *Photonic. Technol. Lett.* **20** 1545
[19] Song Y L, Guo W Z and Wang J P 2008 *Chin. Phys. Lett.* **25** 1274
[20] Ogusu M, Ide K and Ohshima S 2005 *IEICE Trans. Commun.* **E88** 195
[21] Ogusu M, Ide K and Ohshima S 2004 *The 30th European Conference and Exhibition*, September 3, 2004 Stockholm, Sweden, p. 420
[22] Yu J J, Xu L and Yeo Y K 2006 *Photonic. Technol. Lett.* **18** 1524
[23] Tokle T, Serbay M and Rosenkranz W 2006 *The 19th Annual Meeting of the IEEE*, October 29, 2006 Montreal, Canada, p. 490
[24] Lu G W, Deng N and Chan C K 2005 *Optical Fiber Communication Conference and Exposition and the National Fiber Optic Engineers Conference*, March 6, 2005 San Diego, USA, p. OF18
[25] Gao B, Luo H E and Wu G 2007 *Chin. Phys. Lett.* **24** 101