An 80-km-Reach Centralized-light-source WDM PON utilizing Inverse-RZ-Duobinary Downstream Signals

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Abstract *An 80-km-reach WDM PON with 10-Gb/s downstream and 2.5-Gb/s upstream re-modulated signals is demonstrated. The dispersion tolerant Inverse-RZ-Duobinary is employed as the downstream format while upstream ASK re-modulation is performed by reflective SOA.*

Introduction

The wavelength division multiplexed passive optical network (WDM-PON) is an attractive technology to meet the ever-increasing bandwidth demand from enterprises and households. However, the main challenges when deploying this technology in access network consist in the cost and the wavelength-assignment problem of WDM transmitters. One practical 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 optical network units (ONUs) [1]. To achieve further cost savings, long-reach optical access networks are exploited as they offer the potential to reduce bandwidth transport costs by enabling the direct connection of access networks and inner core networks [2]. Therefore long-reach CLS WDM-PON has recently aroused much attention. In realization of CLS WDM-PON, Inverse-Return-to-Zero (Inverse-RZ) and Manchester are among the feasible options for the downstream signal format, since they carry power in both “1” and “0” bits [3] [4]. However, they may not be suitable for 10-Gb/s long-reach PON because of the limited uncompensated transmission distance. Differential phase-shift keying (DPSK) has large dispersion tolerance, but it requires an optical delay interferometer (DI) at each ONU for signal demodulation before detection, which is costly and sensitive to wavelength shift.

In this paper, we experimentally demonstrated an 80-km-reach CLS WDM-PON system with downstream 10-Gb/s Inverse-RZ-Duobinary signal and upstream 2.5-Gb/s re-modulated non-return-to-zero (NRZ) amplitude-shift keying (ASK) signal. The downstream light containing Inverse-RZ-Duobinary signals can be directly reused and-re-modulated with the upstream data at the ONU, without any synchronization procedure. Compared with Inverse-RZ format, Inverse-RZ-Duobinary format has larger dispersion tolerance. Different

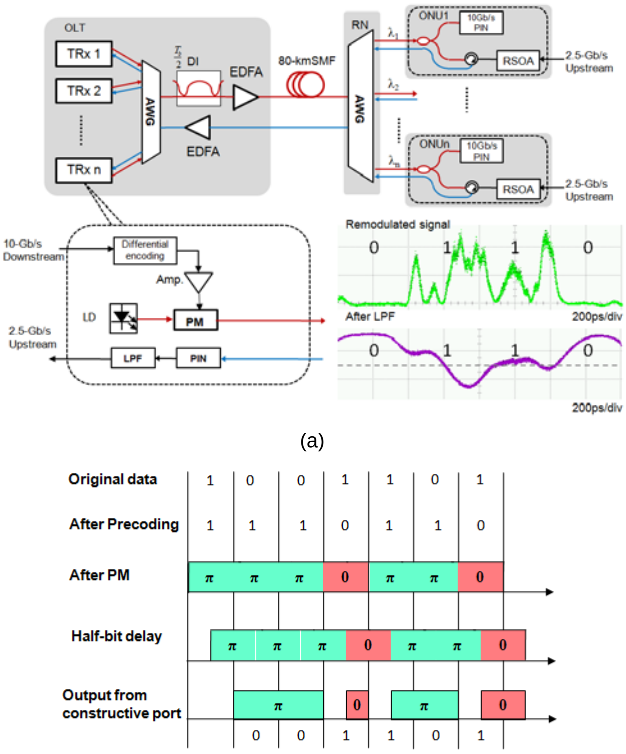

Fig. 1: (a) Architecture of the proposed system. (b) Principle of generating Inverse-RZ-Duobinary signal.

from [5], we propose to generate the Inverse-RZ-Duobinary downstream signal using an optical phase modulator (PM) followed by a half-bit DI at the OLT. This method does not require correlation encoder, as well as high power electrical amplifier to obtain $2V_\pi$ driving voltage, as required in [5], therefore it is more cost-effective and practical.

System architecture

Fig. 1 (a) illustrates the CLS WDM-PON architecture utilizing Inverse-RZ-Duobinary as the downstream signal format. Each transceiver at the OLT generates its downstream Inverse-RZ-Duobinary signal and receives its upstream re-modulated signals from its respective subscriber. At the OLT, differentially pre-coded downstream data is modulated onto a designated wavelength channel through an optical phase modulator. All downstream modulated wavelengths are multiplexed, via an array waveguide grating (AWG), before being fed into a common half-bit DI, where the DPSK signals on all wavelengths are converted into Inverse-RZ-Duobinary signals at the DI's constructive port. Fig. 1(b) illustrates the operation principle of this format conversion from DPSK to Inverse-RZ-Duobinary. In practical application, all laser frequencies should be precisely aligned to the spectral response of the DI to realize such format conversion. By proper setting of the time delay between the two arms in the DI, the duty cycle of the generated RZ signals is set to about 50%. All downstream wavelengths are then delivered to their destined ONUs, via a piece of 80-km feeder fiber and the individual distribution fibers.

At each ONU, a 3-dB optical coupler splits a portion of the received downstream signal power for detection, while the remaining power is fed into a reflective semiconductor optical amplifier (RSOA) for upstream data re-modulation. The finite optical power in each bit of the received downstream Inverse-RZ-Duobinary signal provides the light source for the upstream transmission. After re-modulation, the upstream NRZ-ASK signal was then transmitted back to the OLT, via another upstream fiber link. A pair of feeder fibers is used to avoid the possible Rayleigh backscattering induced performance degradation on both the downstream and the upstream signals. At the OLT, the upstream signal is recovered by an electrical low pass filter (LPF) after detection. Fig. 1 insets show an example waveform of the received upstream signal and its corresponding electrical waveform after the LPF.

Experimental demonstration

The proposed system was experimentally demonstrated on one particular channel for proof-of-concept demonstration. A CW light from a DFB laser at 1550.13 nm was modulated by a 10-Gbs pseudo-random binary sequence (PRBS) downstream data with a length of $2^{31}-1$. The output Inverse-RZ-Duobinary downstream signal was amplified by an erbium-doped fiber amplifier (EDFA) to 6 dBm. After 80-km transmission, a portion of light is fed into the RSOA and re-modulated by 2.5-Gb/s $2^{31}-1$ PRBS upstream data. The modulation condition of RSOA is set to maximize the extinction ratio (ER) of the modulated upstream signal. The upstream signal was then sent back to OLT, via another piece of 80-km fiber. At the OLT, an electrical LPF with 3-dB bandwidth of 1.87 GHz was used

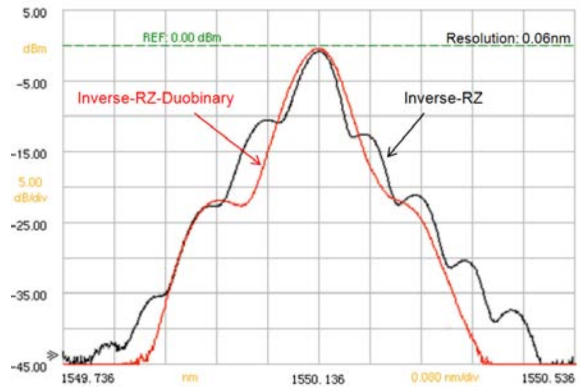

Fig. 2: Optical spectra of conventional Inverse-RZ and Inverse-RZ-Duobinary signals.

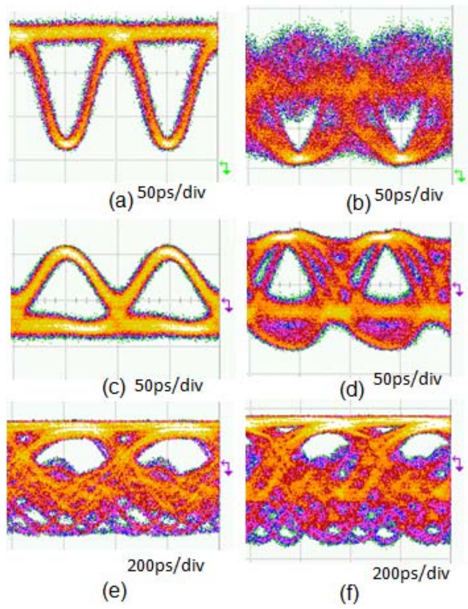

Fig. 3: Eye diagrams of (a) optical BtB Inverse-RZ-Duobinary, (b) optical Inverse-RZ-Duobinary after 80-km transmission, (c) electrical BtB Inverse-RZ-Duobinary, (d) electrical Inverse-RZ-Duobinary after 80-km transmission, (e) electrical BtB remodulated signal, (f) electrical remodulated signal at OLT.

to recover the upstream data.

Fig. 2 shows the optical spectrum of the Inverse-RZ-Duobinary signal generated at the OLT. It has exhibited relatively more compact spectrum, as compared to that of a conventional Inverse-RZ signal. Thus it has better tolerance against fiber chromatic dispersion. Figs. 3 (a) and (b) show the eye diagrams of the generated Inverse-RZ-Duobinary signal, obtained at the constructive output port of the DI, and that after 80-km transmission, respectively. Their corresponding electrical eye diagrams detected by 10-Gb/s receiver followed by an inverting pre-amplifier are shown in Fig. 3 (c) and (d), respectively. Figs. 3 (e) and (f) show the back-to-back (BtB) eye diagram for the upstream signal before and after a 1.87-GHz electrical LPF, respectively. Fig. 4 shows the measured

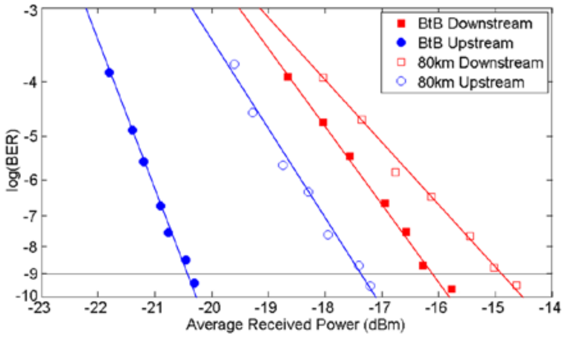

Fig. 4: BER measurements of the 10-Gb/s downstream and the 2.5-Gb/s upstream signals.

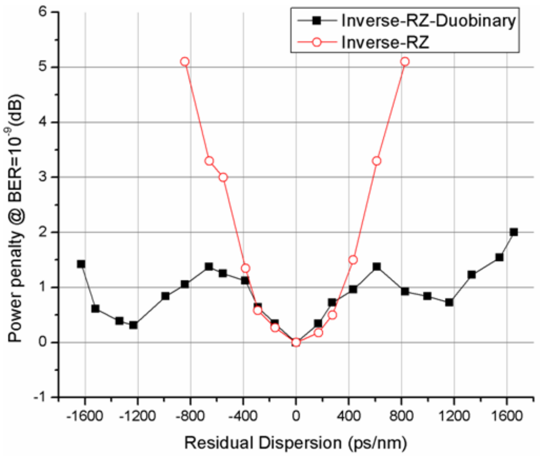

Fig. 5: Measured dispersion tolerance for Inverse-RZ-Duobinary and conventional Inverse-RZ signal.

bit-error-rate (BER) performance. Error-free transmissions were achieved for both the downstream and the upstream signals, after 80.4-km standard single-mode fiber (SSMF) transmission. The BtB sensitivity (at BER of 10^{-9}) for the 10-Gb/s downstream Inverse-RZ-Duobinary signal and the 2.5-Gb/s upstream re-modulated ASK signal were measured to be -16.27 dBm and -20.45 dBm, respectively. After 80.4-km transmission, their respective power penalties were measured to be 1.26 dB and 2.95 dB, respectively.

We have also investigated and compared the dispersion tolerance between the Inverse-RZ-Duobinary format and the conventional Inverse-RZ format. Fig. 5 depicts their respective power penalties (at BER=10^{-9}) measured at different residual dispersions. It was found that the 10-Gb/s Inverse-RZ-Duobinary signal exhibited dispersion tolerance from -1634 ps/nm to +1626 ps/nm, at 2-dB power penalty. However, under the same condition, the conventional Inverse-RZ signal only exhibited dispersion tolerance from -460 ps/km to +500 ps/nm. The measurements showed that dispersion tolerance of the Inverse-RZ-Duobinary format was more than three times superior to that of the conventional Inverse-RZ signal.

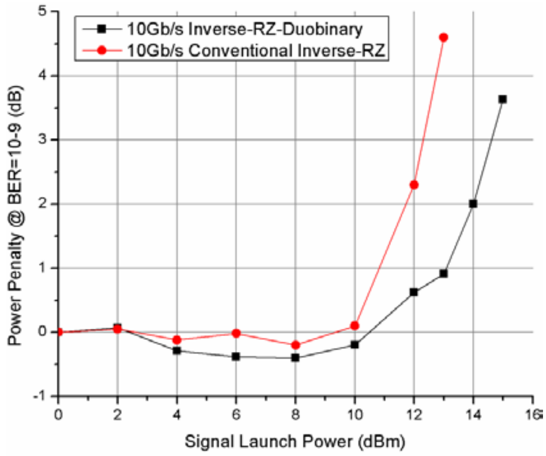

Fig. 6: Measured nonlinear tolerance for Inverse-RZ-Duobinary and conventional Inverse-RZ signal.

As the power budget is another important issue in long-reach WDM-PON, we have further investigated the nonlinear tolerance of the Inverse-RZ-Duobinary signal. The Inverse-RZ-Duobinary signal at different optical powers was launched into a piece of 80-km SSMF so as to evaluate the nonlinear tolerance. The chromatic dispersion of the SSMF was compensated with dispersion compensate module (DCM). The receiver sensitivities (at BER of 10^{-9}) of both 10-Gb/s Inverse-RZ-Duobinary signal and 10-Gb/s conventional Inverse-RZ signal, at different launched power levels were measured and their induced power penalties were shown in Fig. 6. The results also proved that the Inverse-RZ-Duobinary format has much better nonlinear tolerance and it exhibited 1-dB penalty at 13-dBm launched power.

Summary

We have experimentally demonstrated and characterized an 80-km-reach CLS WDM-PON. By employing the dispersion tolerant Inverse-RZ-Duobinary as downstream format, 10-Gb/s downstream and 2.5-Gb/s upstream transmission over 80 km is realized. Error-free transmissions for both the downstream and the upstream signals have been achieved without dispersion compensation.

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