Symmetric 10 Gbit/s WDM-PONs with Remote Pumping and Channel Fault Monitoring

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Abstract

Symmetric 10-Gb/s WDM-PONs is realized with REAMs as colorless ONUs and ASE source for channel fault monitoring. The remotely pumped scheme is used to simultaneously enhance up- and down-stream signals and monitoring signals.

1. Introduction

WDM-PONs with loop back re-modulation as the colorless transmitter at an optical network unit (ONU) is a promising solution for the high-bandwidth access networks [1]. Among the candidates for colorless transmitters at ONUs, the reflective electro-absorption modulators (REAMs) can be easily scaled for a data rate higher than 10 Gbit/s, comparing to the RSOAs or IL-FPLDs [2]. The drawback of REAMs is its high insertion loss [3].

For a WDM-PON system carrying high capacity data, its system reliability has to be concerned. Therefore, the channel fault monitoring must to be implemented on the system. Using an amplified spontaneous emission (ASE) source as the monitoring signal source for a WDM-PON can be simple and low cost, but it can suffer from poor signal quality due to the high loss from spectral slicing by the AWG and reflective mirror in the ONU[4].

We proposed a 10-Gb/s bidirectional transmission WDM-PON architecture with remotely pumping scheme channel fault monitoring capability [5]. A single pump source is used to simultaneously boost the signal strength for the downstream (DS) and upstream (US) signals as well as the monitoring signals. In this paper, we will report the system performance for a WDM-PON system that utilizes the similar technology but with different wavelength arrangement.

Fig. 1 shows the schematic of the proposed WDM-PON system. The wavelength arrangement for the bidirectional transmission signals and monitoring signals is depicted in Fig. 2. In our previous work, both DS and US channels are squeezed in the C-band of DWDM channels for easy implementation of optical gain. In order to accommodate more US and DS channels, here the US and DS channels are allocated in the C- and L-bands, respectively. The wavelength bands are spaced by integer multiplicity of free spectral range (FSR) of the AWG such that the DS, US, and monitoring signals for the same user can all pass through the same port of the AWG. Both the US and monitoring signals will be amplified by the remotely pumped EDFA (RP-EDFA), while the DS signals will be enhanced by Raman gain from the same pumped laser.

At the center office (CO), besides the DWDM transmitters for sending DS signals, continuous-wave (CW) DWDM sources are used as the seeding lights for the REAMs at ONUs to encode US signals. We added an erbium doped fiber (EDF) at the remote node (RN), which is remotely pumped by a high power pumping laser of around 1480-nm wavelength. An ASE source is also added for detecting the fiber fault of the feeder fiber and distributed fibers. The ASE source is spectral sliced by the AWG at RN, distributed to the ONUs and then reflected back to CO by an optical mirror (M). When a distribution fiber is broken, the reflected sliced ASE spectrum for the corresponding channel will be missing at the monitoring receivers at CO.

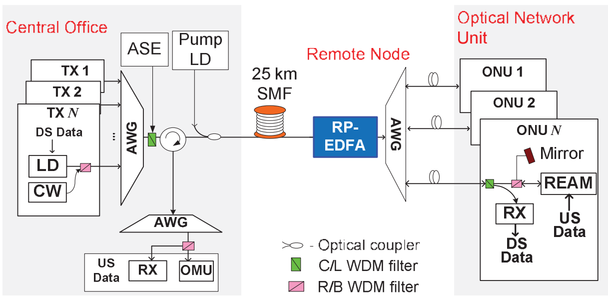

Fig. 1 Bidirectional WDM-PON architecture with channel fault monitoring and a remote pump source.

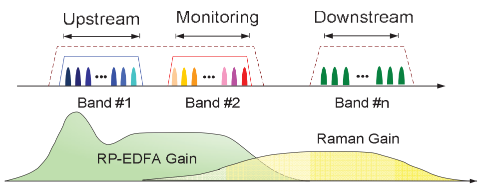

Fig. 2 Wavelength arrangement for bidirectional signal transmission and channel fault monitoring.

For US transmission, each seeding light is amplified by the RP-EDFA, modulated by the REAM, and then amplified by the RP-EDFA again before receiving at CO. Since the pump power propagates along the same feeder fiber as the signal channels, Raman amplification can also be exploited to amplify the DS signals. The DS channels do not pass through the EDF in order not to suppress the gain for US and monitoring signals.

2. Experiment and results

Fig. 3 shows the experimental setup for the WDM-PON system. For the L-band DS transmission, two DFB lasers with 1592.51 nm and 1594.1 nm wavelength are modulated by a $LiNbO_3$ modulator with a 10 Gb/s 2^{31}-1 NRZ PRBS pattern to simulate two DS channels. The extinction ratio (ER) is set as 11 dB for both channels. The average transmitted power is -1 dBm. Two CW lasers of 1540.4-nm and 1541.98-nm wavelengths are used as the seeding light for US transmission. Their output power is about +7 dBm.

The channel monitoring light source is confined between 1560 and 1580 nm by filtering the broadband ASE with a coarse WDM (CWDM) filter. The total output power of the monitoring source measured at the output of the optical circulator is -10 dBm. Fig. 4(a) shows the spectrum of the combined signals at the output of the circular (point A). Two mirrors with > 90% reflectivity are used to feed back the monitoring signals to the CO for the two ONUs. A cyclic AWG with 100-GHz channel spacing and 25.6-nm FSR is used at the RN. The average insertion loss of the WGR is 6 dB. The output power of the pump laser is set at 280 mW.

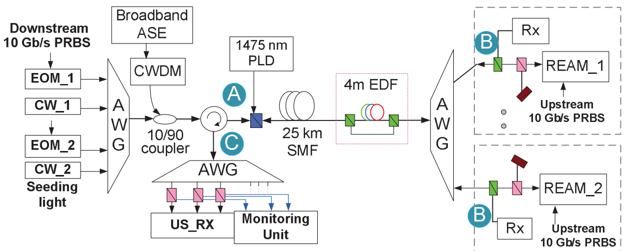

Fig. 3 Experimental setup.

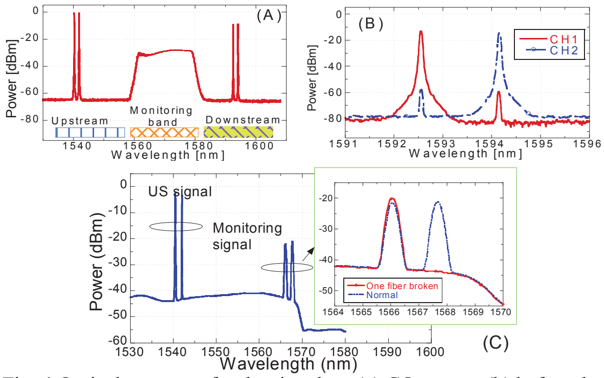

Fig. 4 Optical spectrum for the signals at (a) CO output, (b) before the DS receiver, and (c) detailed monitoring signals

The two DS signals reach RN with optical power of -13.2 dBm and -14.4 dBm, respectively. For US transmission, the CW lights from CO are directed to the corresponding ONUs and remodulated by REAMs with 10-Gb/s PRBS (2^{31}-1) signals. The injection power to the REAM is +5 dBm. Their insertion loss is about 11 dB under modulation. The output ER of the two REAMs is 9 dB. The upstream signals can be respectively amplified to -1.58 and -1.35 dBm by the RP-EDFA. Fig. 4(b) compares the two DS signals spectra. The DS signals have > 40 dB OSNR. The received monitoring signal power is about -21 dBm with large than 20 dB OSNR. When a distribution fiber to an ONU2 is broken, the corresponding spectral peak disappears in the detected spectrum, as indicated clearly in Fig. 4(c).

Fig. 5 (a) and (b) depict the measured BER curves for the DS and US signals with the RP-EDFA. The DS signals have clear eye-openings even after 25-km transmission. The power penalty is less than 1 dB. For the US signals after 25-km transmission, it suffers from <2 dB of power penalty, which results mainly from the effects of Rayleigh and Fresnel backscattering (RBS). From the eye-diagram after 25-km SMF transmission, the mark level of the US signal reveals larger noise accumulation. The RBS effects can be reduced by eliminating the unwanted Fresnel reflections and optimizing the gain of the RP-EDFA.

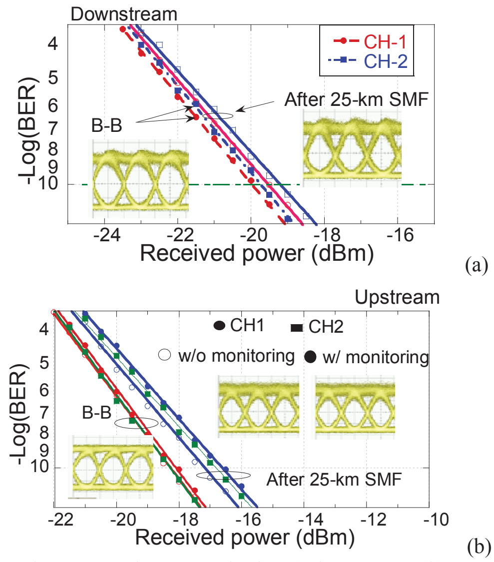

Fig. 5 The measured BER results for (a) downstream (b) upstream transmissions and the corresponding eye-diagrams under w/ and w/o monitoring signals.

3. Conclusions

By rearranging the wavelength plan, the remote pumping scheme can simultaneously compensate the double path loss for the signal transmission and enhance the signal to noise ratio for the fiber fault monitoring. The scheme requires a minor addition of photonic components from the conventional architecture but improves the system performance significantly.

4. Acknowledgment

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5. References

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