Remotely Pumped WDM-PONs for Bidirectional 10-Gb/s Transmission with Channel Fault Monitoring

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Abstract: WDM-PONs for 10-Gb/s bidirectional transmission are realized with REAMs as ONUs and ASE source for channel fault monitoring. The remotely pumped scheme can simultaneously boost up- and down-stream signals and enhance OSNR of monitoring signals.
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1. Introduction

Wavelength-division-multiplexed passive optical networks (WDM-PONs) are emerging as the choice for future broadband access networks to provide large-capacity, flexible, and secure services. To fulfill future bandwidth requirement, 10 Gb/s per user or even higher data rate is desired for both downstream (DS) and upstream (US) services. Reflective electro-absorption modulators (REAMs) are often selected as the colorless transmitters at optical network units (ONUs) to carry 10 Gb/s signals [1]. In order to meet the required power budget when REAMs are used, optical amplification has to be included at the ONU [2,3]. A remotely pumped EDFA can also be used at the remote node to boost the signal amplitude [4]. On the other hand, for a WDM-PON system carrying high-capacity data, its system reliability has to be assured. Therefore, the channel fault monitoring has to be added in 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 loss from spectral slicing [5].

In this paper we proposed a simple WDM-PON architecture to provide 10-Gb/s bidirectional transmission and channel fault monitoring. A remotely pumping scheme is used to simultaneously boost the signal strength for the DS and US signals as well as the monitoring signals.

2. System architecture and operation principle

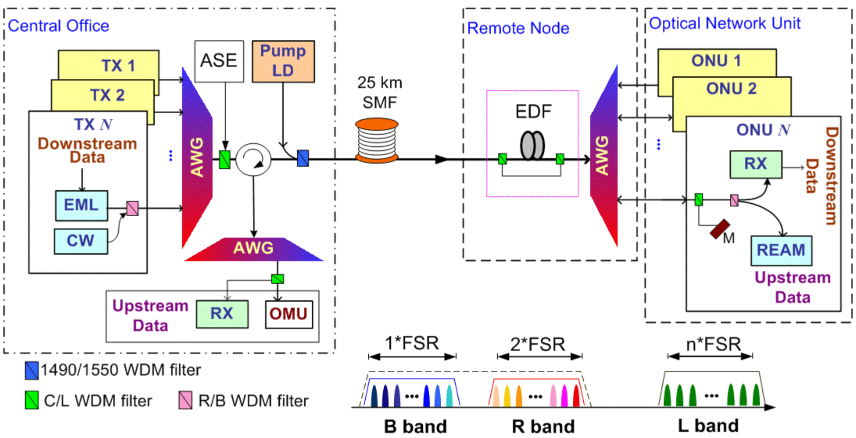

Fig. 1. Bidirectional WDM-PON architecture with channel fault monitoring and a remote pump source.

Fig. 1 shows the system architecture for the WDM-PON system. The DS/US channels and monitoring channels are arranged at different wavelength bands. 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. The DS signals are simply transmitted by DWDM transmitters, while continuous-wave (CW) DWDM sources are used at the center office (CO) as the seeding lights for carrying US signals via the REAMs. Comparing to a conventional WDM-PON system, we added at the remote node (RN) an erbium doped fiber (EDF), which is remotely pumped by a high power laser of around 1480-nm wavelength. An ASE source is also added at the CO for detecting the fiber fault of the feeder fiber and distributed fibers. The ASE source is distributed to the

ONUs by the AWG demultiplexer at RN and reflected back to CO by an optical mirror (M) at each ONU. When a distribution fiber is broken, the reflected sliced ASE spectrum for the corresponding channel will be missing at the monitoring receivers, locating at CO. Both the DS and US signals will be amplified by the remotely pumped EDFA (RP-EDFA). For US transmission, each seeding light is amplified by the RP-EDFA, modulated by the REAM, and then amplified by the RP-EDFA again. The reason to place the optical amplifier near ONU instead of CO is to obtain good optical signal to noise ratio (OSNR) for the US signal. By using the remote pumping scheme, the remote node can remain passive, with no need of electric power.

In order to boost the signal strength of the monitoring signal, the ASE wavelength band is chosen at the wavelength band in which the Raman amplification can be provided by the same pumping source. By using such an arrangement, the monitoring signal can be enhanced without using additional optical amplifiers or pumping sources. Since the monitoring source is amplified by the Raman gain, it does not pass through the EDF in order not to suppress the gain for DS and US signals. Subject to the operation wavelengths of current commercial available photonic components, especially REAMs, we divide the C-band into B(blue)- and R(red) bands for transmitting upstream and downstream signals, respectively. The monitoring sources are arranged at the L-band.

3. Experimental demonstration

Fig. 2 shows the experimental setup for the WDM-PON system. For the R-band DS transmission, two electro-absorption modulated DFB lasers (EML) are modulated at 10 Gb/s using 2^{31}-1 non-return to zero (NRZ) pseudo random binary sequence (PRBS) pattern to simulate two DS channels. Their wavelengths are 1550.76 nm and 1552.36 nm, respectively. The extinction ratio (ER) is set as 9.8 dB for both channels. The average transmitted power is -3.8 dBm. Two CW B-band lasers of 1540.44-nm and 1542.05-nm wavelengths are used as the seeding light for US modulation. The output power of the seeding light is 7 dBm and 6.5 dBm, respectively.

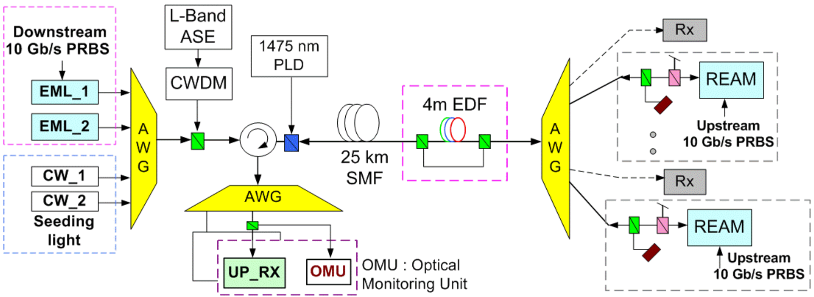

Fig. 2. Experimental setup.

A tunable optical attenuator is added after the AWG at CO to control the total power of all channels at 2.5 dBm. The L-band channel monitoring light source is confined within the wavelength range between 1580 and 1600 nm by filtering the broad-band ASE with a coarse WDM (CWDM) filter. The total output power of the monitoring source is +6.2 dBm. Fig. 3(a) shows the spectrum of the combined signals. The pump laser is of 1475.75-nm wavelength and 280-mW output power. A cyclic AWG with 100 GHz channel spacing and 26 nm FSR is used at RN. The average insertion loss is 6 dB. The separation from CO to RN is 25 km, leading to a fiber loss of 5.5 dB. The pump laser provides about +5 dB Raman gain for the monitoring signals. After 25-km SMF transmission, the pump power into the 4-m long EDF is about 45 mW. Due to lack of enough DWDM lasers of specific wavelengths in our laboratory, the wavelengths of the R-band channels and B-band channels are not spaced by a FSR. To proof of the concept, the received signals pass through different AWG ports and directed to the ONUs with different distribution fibers.

The two DS signals reach RN with optical power of -14.2 dBm and -13.7 dBm, respectively, and their power rises to -1.86 dBm and -1.58 dBm, respectively, after the RP-EDFA. 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 +4 dBm. The optimal operation wavelength for the REAMs is between 1525 and 1555 nm. Their insertion loss is about 11 dB under modulation. The output ER of the two REAMs is 7.6 dB and 7.3 dB, respectively. T he upstream signals can be respectively amplified to -3.75 and -2.4 dBm by the RP-EDFA. Two mirrors of 92% and 99% reflectivity are used to feedback the monitoring signals for the two ONUs.

Fig. 3(b) compares the signal spectra with and without RP-EDFA. The US signals benefit clearly from the optical amplification. Without the amplification, the US signals suffer from > 40 dB loss for the conventional REAM-based WDM-PON, counting for the transmission of seeding light, REAM remodulation, and the transmission back to CO. The large loss will make the signal detection difficult. The situation is similar for the monitoring signals. From the spectra shown in Fig. 3(b), the received monitoring signal power is about -38 dBm with 11.8 dB OSNR when there is no remote pump. Such low signal level is tough for fiber fault detection. The monitoring power level and OSNR can be improved to -26.6 dBm and 18 dB by using the RP-EDFA technique. When a distribution fiber to an ONU is broken, the corresponding spectral peak disappears in the detected L-band spectrum, as indicated clearly in Fig. 3(c).

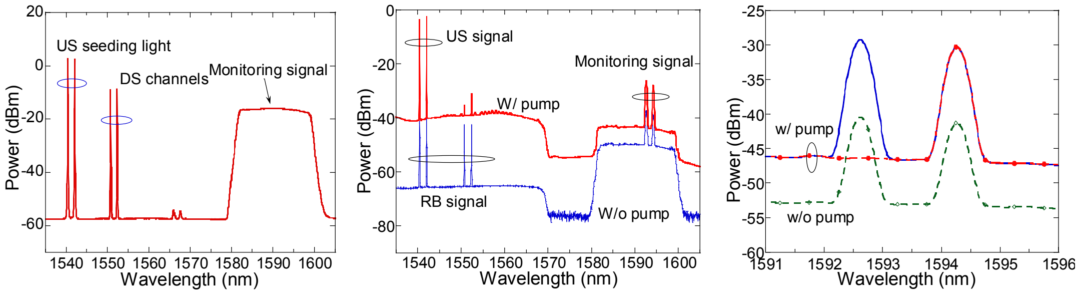

Fig. 3. Optical spectrum for the signals at (a) CO output, (b) before AWG of CO receiver, and (c) detailed monitoring signals

Fig. 4 (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 due to fiber dispersion and amplifier noise is less than 1.1 dB. For the US signals after 25-km transmission, it suffers from about 2.2 dB of power penalty, which results mainly from the effects of Rayleigh and Fresnel backscattering (RBS). For our experimental conditions, the RBS from the feeder fiber is relatively small, comparing to the RBS between RN and ONUs, where the RBS bounces back and forth and amplified by the RP-EDFA. 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.

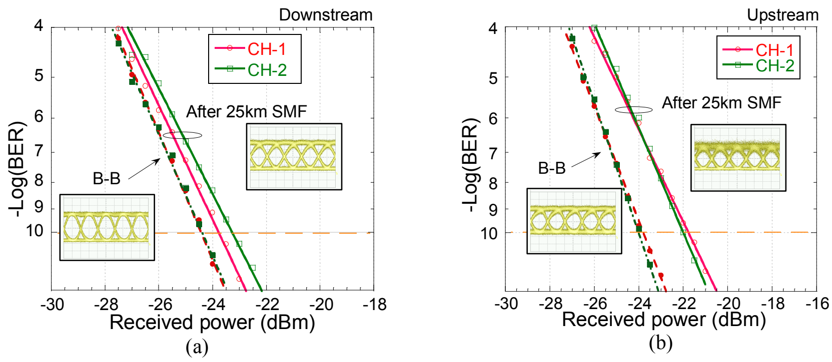

Fig. 4. The measured BER results for 10 Gb/s (a)downstream and (b) upstream transmissions and the corresponding eye-diagrams.

4. Conclusions

We propose and experimentally demonstrate a remotely pumped WDM-PON architecture to provide bidirectional 10Gb/s transmission capacity with fiber fault monitoring capability. 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. The amplifier gain can be further increased and/or flattened if needed by using a higher-power pumping source or multiple pumps.

5. References

[1] G. Berrettini et al., "Colorless WDM-PON performance improvement exploiting a service-ONU for multiwavelength distribution," OFC/NFOEC, OMN2, 2009.

[2] E.K. MacHale et al., "Signal-induced rayleigh noise reduction using gain saturation in an integrated R-EAM-SOA," *OFC/NFOEC*, OThA6, 2009.

[3] D. Smith et al., "Colourless 10Gb/s Reflective SOA-EAM with low polarization sensitivity for long-reach DWDM-PON networks," ECOC, Paper 8.6.3, 2009.

[4] Y.-S. Huang et al., "10Gb/s bidirectional long reach WDM-PON with dispersion compensating Raman/EDFA hybrid amplifier and colorless ONUs," OECC, 6A2-4, 2010.

[5] S.-B. Park et al., "Optical fault monitoring method using broadband light source in WDM-PON," Electron. Lett., vol. 42, no. 4, pp. 239-241, 2006.