Long-Reach WDM PONs

(Invited)

C. W. Chow[1]*, C. H. Yeh[2]

[1]Department of Photonics, Institute of Electro-Optical Engineering, National Chiao Tung University, Taiwan
[2]Information and Communications Research Laboratories, Industrial Technology Research Institute, Taiwan
Tel: +886-3-5712121 e-mail: cwchow@faculty.nctu.edu.tw

Abstract— **We discuss recent progress in the research of the optically amplified, long-reach WDM PONs, which aim to reduce the cost and the complexity of future fiber-to-the-home systems.**

I. Introduction

Passive optical networks (PONs) are being deployed in many countries to meet the emerging broadband services requirement by end-users. The most advanced of these (GPON, GEPON and 10GEPON) have been standardized and commercially available. In order to significantly reduce the cost, complexity and power consumption of the present PONs, long-reach (LR) PONs have been proposed [1-4]. LR-PON usually requires the following key features:

- Long distance (~60-100 km): LR-PON can integrate the metro and access networks into a system to reduce the number of network elements and interconnection interfaces. Optical amplifiers are usually needed.
- High split-ratio: This can maximize the utilization and sharing of equipments and optical fiber.
- High data rate: This can increase the bandwidth per customer to meet the bandwidth demand in the future.
- Using wavelength division multiplexing (WDM): This can improve the bandwidth utilization of optical fiber.

In this paper we will discuss the recent progress in the research of WDM LR-PON. Some key design issues of the physical layer implementation of the LR-PON are outlined. The challenges and possible solutions are discussed.

II. System Design Issues

A. Colorless RONU

In WDM LR-PON, one of the challenging issues is to simplify the administration of the wavelength assignment to different optical networking units (ONUs). Using tunable laser source in each ONU is still too expensive nowadays. Hence, using wavelength-independent (or colorless) reflective (R) ONU with optical carrier distribution could be a promising candidate. This can reduce the inventory cost since the same components can be used in each RONU in the networks. Besides, the optical equipments, such as laser source can be shared by all the RONUs in a time-division-multiplexed (TDM) PON.

Fig. 1 shows one of our proposed system architectures. One advantage of this architecture is that all the WDM components are located in relatively controlled environments, in the remote node (RN) and the central office (CO), where electrical power supply for the optical and electronic components is already present. For the upstream signal (US), a continuous wave (CW) optical carrier is distributed from the RN to the RONU via passive fiber splitter and 25 km distribution and drop fibers. The generated US are then transmitted to the CO via the 25 km and 75 km single mode fiber (SMF). The downstream signal (DS) is sent from the CO using another wavelength.

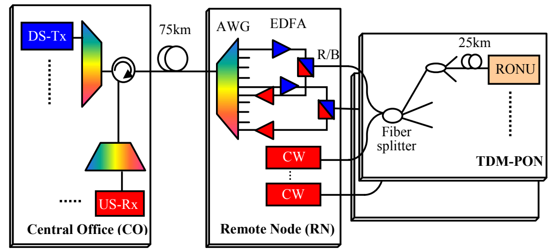

Fig. 1. Proposed architecture of the WDM LR-PON.

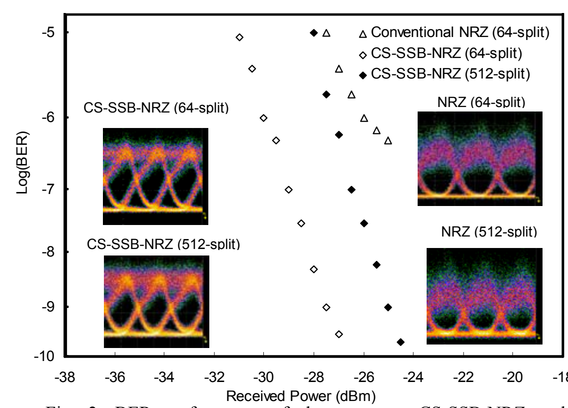

Fig. 2. BER performance of the upstream CS-SSB-NRZ and conventional NRZ signals in the LR-PON.

Although the carrier distribution scheme provides many advantages as mentioned above, it will produce Rayleigh backscattering (RB) noise at the upstream receiver (US-Rx) at the CO. For effective RB mitigation, we can reduce the spectral overlap between the US and the RB. Hence the beat noise will fall outside the Rx bandwidth. We have proposed several solutions to mitigate the RB noise, including:

- Using carrier suppressed single sideband (CS-SSB) modulation at the RONU [5].
- Using carrier suppressed subcarrier-amplitude modulated phase shift keying (CSS-AMPSK) at the RONU with offset-filtering at the CO [6].

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- Using phase-modulation induced spectral broadening at the RONU [7].
- Using wavelength splitting at the RN [8].

Fig. 2 shows the bit-error-rate (BER) performances of the upstream CS-SSB-NRZ (2.5 Gb/s data with SSB of 10 GHz away from the carrier wavelength) and the conventional NRZ in the proposed LR-PON (Fig. 1). The CS-SSB-NRZ signal shows error-free at split-ratio of 512. The conventional NRZ shows an error-floor at BER of 10^{-7} with a split-ratio of 64; and BER cannot be measured at a split-ratio of 512. The measurement results show that the CS-SSB-NRZ signals significantly mitigate the RB noises.

B. Dispersion Compensation in LR FiberLlink

In the LR-PON, it is difficult to fully dispersion compensate the long reach fiber link since the distances between the CO and each ONU will vary. Hence chromatic dispersion tolerance is another important issue for LR-PON, particularly at bit rate of 10^{+} Gb/s. We have proposed using optical orthogonal frequency division multiplexing (OFDM) in the LR-PON. The OFDM frequency diversity transmission allows simple equalization of frequency response by baseband digital signal processing. It can be used to mitigate fiber chromatic dispersion. Negligible power penalty was observed in back-to-back, 50 km and 100 km SMF transmissions without any dispersion compensation [9]. The RB performance [10] and the possibility of signal remodulation in the LR-PON using OFDM [11] have also been discussed.

We have also proposed using CSS-AMPSK signal for the LR-PON. The CSS-AMPSK signal was generated by effectively duobinary filtering of the non-return-to-zero (NRZ) signal and RF up-conversion. Hence the optical spectral width of the CSS-AMPSK signal is about 1/4 of the NRZ signal. The dispersion penalty of the 10 Gb/s CSS-AMPSK was measured to be about 2 dB at BER of 10^{-9} after 120 km SMF transmission without dispersion compensation [6].

C. Increase Data Rate

Besides having strong chromatic dispersion tolerance, OFDM signal with quadrature amplitude modulation (QAM) format used in each subcarrier can be highly spectral efficient. This means we can directly increase the data rate of the PON while using the existing optical components developed for the GPON. We have demonstrated using 1 GHz bandwidth direct modulated laser for 4 Gb/s 16-QAM OFDM LR transmission [9]. 10 Gb/s and 100 Gb/s OFDM signal can be generated by using 2.5 GHz and 40 GHz bandwidth optical components [12]. Furthermore, by controlling the power in each of the OFDM subcarrier, frequency ripple issue caused by low-cost components can be mitigated.

D. Gain Transient and Tilting in Optical Amplifiers

Due to the high power losses of the LR transmission link and high split-ratio, optical amplifiers, such as erbium doped fiber amplifiers (EDFAs) are usually included in the LR-PON. However in the hybrid WDM-TDM architecture, the gain dynamic of the EDFA may greatly affect the network performances. Gain tilting may occur when one or more WDM channel(s) are switched off, and this will result in excessive power at one end of the gain spectrum of the EDFA. Besides, the burst-mode nature of the US in the TDM PON will also lead to transient power fluctuation in the EDFA amplified signal. These effects will produce excessive power to the Rx at CO, making the received optical signal outside the dynamic range or even damage the Rx. Hence, we have proposed and demonstrated using ion-implantation silicon waveguide for in-line channel power monitoring [13]. We have also demonstrated by using silicon based power monitor and variable optical attenuator (VOA) to suppress the gain transient of the optical US [14]. The silicon based power monitor, VOA can be monolithically integrated with the silicon based arrayed waveguide grating (AWG).

III. CONCLUSION

We discussed recent progress in the research of the WDM LR-PONs. Some key design issues are outlined. The challenges and some possible solutions are discussed.

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