RSOA-based distributed access long reach hybrid WDM-TDM PON with OADMs

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A distributed access scheme using optical add/drop multiplexers (OADMs) for long reach hybrid wavelength division multiplexing and time division multiplexing passive optical networks (WDM-TDM PONs) is proposed and demonstrated. Colorless operations are implemented by using commercially available reflective semiconductor optical amplifiers (RSOAs) at both the center office (CO) and the customer side. Four 1.25-Gb/s channels are successfully transmitted over 80-km single-mode fiber with four OADMs. The dynamic input power range of the RSOA is also investigated. Compared with traditional access schemes, the proposed scheme could cover the area along the feed fiber with no blind zone. The experimental results show that it could be an ideal solution for the next generation access networks.

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For optical access networks, the development trend is to simplify the overall network while economically providing wider bandwidth and accommodating more subscribers[1]. Long reach passive optical network (LR-PON) based on hybrid wavelength division multiplexing (WDM) and time division multiplexing (TDM)[2] has been proposed to achieve this target. By providing extended coverage, LR-PON combines optical access with metro networks into an integrated system. Thus, cost saving is also achieved by simplifying the network, reducing the numbers of equipment interfaces, network elements, and even nodes. By using a centralized light source at the headend office, the same colorless optical network units can be used for all the customers so that the system cost can be reduced. Compared with the structure of directly modulated reflective semiconductor optical amplifier (RSOA), the structure of high-speed semiconductor optical amplifier/electroacoustic modulator (SOA-EAM) devices at 10 Gb/s[3] would be complex to some extent. As other main proposals for the colorless transmitters, the injection-locked Fabry-Perot laser diode would suffer from the polarization dependent gain[4], and the spectrum-sliced broadband light source would be limited by the effects of chromatic dispersion[5]. A RSOA directly modulated at 1.25 Gb/s has been regarded as a cost-effective colorless transmitter for commercial applications[6]. Moreover, a long-distance fiber is adopted as the feed fiber in traditional LR-PON architectures. Only those users located at the end of the fiber are considered, and hence the area along the feed fiber becomes the blind area.

In this letter, we propose and demonstrate a RSOA-based distributed access hybrid LR-PON (LR-HPON). By utilizing an optical add/drop multiplexer (OADM) chain, four access nodes are inserted into the feed fiber at intervals of 20 km. Four 1.25-Gb/s downstream (DS) and upstream (US) signals are successfully transmitted with the maximum transmission distance of 80 km. Furthermore, the design of the fixed OADM can be easily implemented using simple add/drop filters. Commercially available RSOAs and add/drop filters show good performance in our proposed system.

Figure 1 presents the architecture of the proposed distributed access LR-HPON. Four OADM nodes spaced at an interval of 20 km and four symmetrical channels are considered to verify the feasibility of the proposed scheme. In particular, the wavelength channels are 1534.25−1543.73 nm and 1546.92−1556.55 nm for DS channels ($\lambda_{\rm d1},\cdots,\lambda_{\rm d4}$) and US channels ($\lambda_{\rm u1},\cdots,\lambda_{\rm u4}$) with 400-GHz channel spacing, respectively. At each OADM node, a 1:128 passive splitter composed of 1:8 and 1:16 splitters is employed for the cost and bandwidth sharing. The RSOAs used as colorless transmitters in the system are all directly modulated at 1.25 Gb/s (non-return-to-zero (NRZ), pseudo random bit sequence (PRBS) length of $2^{23}-1$). The seed lights for DS modulation are generated by a multi-wavelength source on the optical line terminal (OLT) side, while four cooled distributed feedback (DFB) lasers that supply the seed lights for US channels are located in the four OADM boxes. The impairments introduced by Rayleigh backscattering (RB)[7] are mitigated by changing the position of DFB lasers from the center office (CO) to the OADM boxes. Each seed light is fed into the RSOA through a circulator.

The DS signals are generated by directly modulated RSOAs. The seed light power is adjusted to −10 dBm before being injected into the RSOA for better optical signal-to-noise ratio (OSNR). These signals of four DS channels are multiplexed and transmitted through the OADM chain. At each OADM node, the desired wavelength is dropped by the OADM. Before arriving the optical network units (ONUs), these optical signals must suffer the huge losses introduced by the transmission fiber and the high split rate. Therefore, a commercial erbium-doped fiber amplifier (EDFA) is inserted in

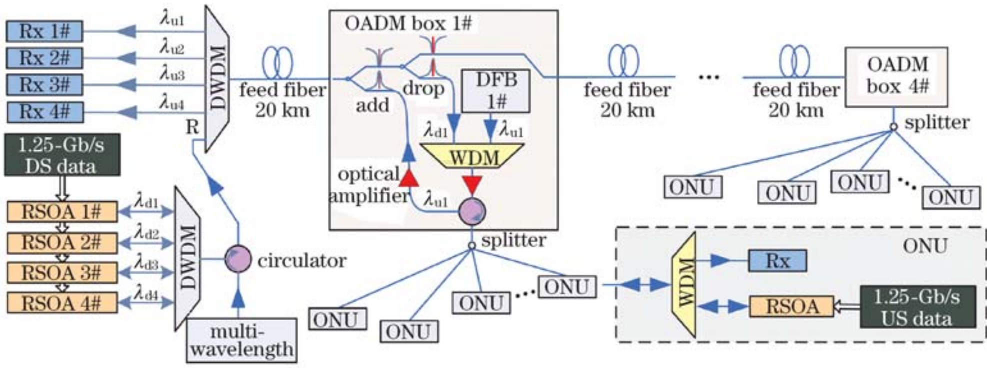

Fig. 1. Architecture of distributed access LR-HPON with OADMs. Rx: receiver; DWDM: dense wavelength division multiplexer; ONU: optical network unit.

front of the splitter to compensate the optical power to −2.5 dBm. After being broadcast by the 1:128 splitter, these signals are separated by WDM and detected by cheap positive-intrinsic-negative (PIN) diodes.

For the US signal, the seed light launched from the DFB laser should also be amplified to compensate the loss of the splitter. Consequently, the EDFA in each OADM box is shared by this US seed light and the DS light for cost saving. After passing the splitter, the seed light is extracted from the mixed lights and injected into the RSOA, and then, it is modulated by the US data, amplified and reflected into the fiber. In the OADM box, these US signals are injected into the add port of the OADM, directed by the circulator in each OADM box. A demultiplexer at CO enables the detection of each wavelength separately with a PIN.

One of the key features in our proposed scheme is OADM, an important network element allowing the management of wavelength in networks. Compared with the expensive reconfigurable OADM used in backbone and metro network, the fixed OADM proposed here is a simple configuration consisting of dense WDM devices.

All the RSOAs employed in this system are the commercial available devices SOA-RL-OEC-1550-CO produced by CIP technology, with low polarization dependence (~1 dB). The electrical PRBS signals are generated by the bit error rate tester (BERT) G-BERT 4250A and the optical signals at receiver (Rx) positions are received by the 1550 transceiver of the BERT.

Figure 2 shows the bit error rate (BER) measurement results of the DS and US transmissions, and the insets are the measured error-free eye diagrams at the target BER of 10^{-10} according to the standard of gigabit-capable PON[8]. The DS BER curves are similar, and there is only a small sensitivity difference of 0.4 dB among four channels, due to the identical input power of four RSOAs in CO. Moreover, the power penalty after an 80-km transmission is negligible due to the power compensation by the EDFA. Nevertheless, attributed to the different input powers of the RSOA in ONU, the US sensitivity difference is slightly increased to 0.7 dB. The eye diagram mask test is performed by the Tek CSA7404B communications signal analyzer. Although a smaller data dependent jitter can be observed maybe due to the mistermination of differential loads in the driver circuit, all the eye patterns in the insets of Fig. 2 are clearly open and compliant with the 1000B-SX/LX/PX (1.25 Gb/s) eye mask defined in 802.3z standard[9].

The extinction ratio (ER) and quality factor Q-factor effects on system performance are depicted in Fig. 3. By changing the position of the US seed light from CO to the OADM box, the RB effect is significantly reduced. Therefore, the ER and Q-factor deterioration of US signals is small enough to be neglected compared with the DS signals. Because the DFB laser has very narrow linewidth, the penalty owing to dispersion effect is almost negligible after the 80-km transmission.

The key challenge in the proposed scheme is the different input powers of the RSOAs in ONUs, induced by the different distances between the splitter and each ONU. This power difference will lead to the ER degradation and the high performance requirements of the OLT's receivers. To analyze the input tolerance of the RSOA in the system of Fig. 1, a variable attenuation instead of

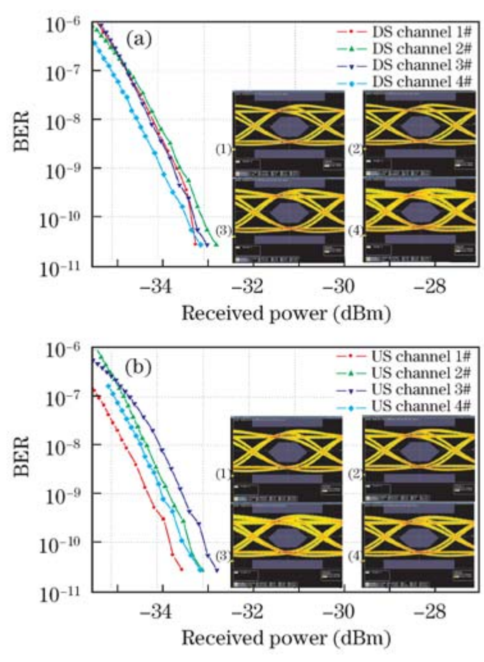

Fig. 2. BER versus received power for (a) DS and (b) US of the four channels. Insets: eye diagrams of (1) channel 1 after 20-km transmission, (2) channel 2 after 40-km transmission, (3) channel 3 after 60-km transmission, (4) channel 4 after 80-km transmission.

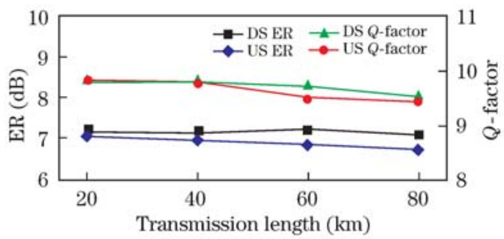

Fig. 3. ER and Q-factor versus transmission length at BER of 10^{-10}.

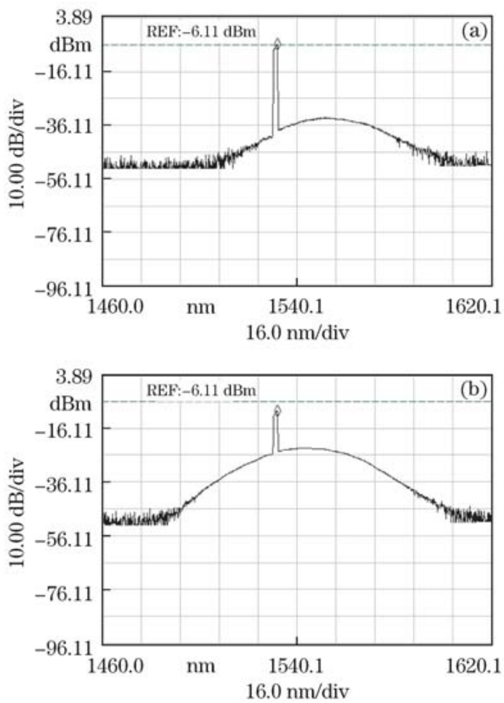

Fig. 4. Reflective spectra of the RSOA with input power of (a) −1.70 dBm and (b) −21.11 dBm.

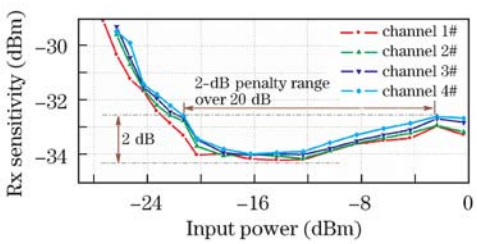

Fig. 5. Rx sensitivity of US signals for four channels.

the 1:128 splitter is inserted before the RSOA to change the input power. Figure 4 indicates the output spectra with different input powers by Agilent 86140B optical spectrum analyzer. When the input power decreases, the peak power at the seed wavelength is slightly decreased while the power of the amplified spontaneous emission (ASE) is enhanced significantly. Correspondingly, the system performance will be much more sensitive to the dispersion effect. The Rx sensitivities of US signals under different input powers of RSOAs are presented in Fig. 5. The curves of four channels are analogous and a maximum sensitivity divergence is 1 dB when the input power is set between −24 and 0 dBm. The minimum Rx sensitivity is at the input power of −12 dBm. Moreover, the sensitivity is only increased by 2 dB even when the input power of the RSOA is increased to −2.2 dBm or decreased to −21.3 dBm. Therefore, the input power dynamic range of the RSOA in uplink channels is about 19 dB, which can easily meet the demands in most practical application scenarios.

The main advantage of this scheme is that an OADM node can be flexibly inserted into the transmission link at any position and the bandwidth will be easily broadened by adding new channels with different wavelengths. It will enhance the flexibility of system deployment in practical applications.

In conclusion, a RSOA-based distributed access LR-HPON is proposed and demonstrated. Four access nodes are distributed into the 80-km transmission fiber through the OADM chain. Compared with the reported schemes, the proposed scheme can cover all the blind area along the feed fiber. A dynamic input range over 19 dB is obtained and the dispersion penalty over 80-km transmission can be neglected. These experimental results demonstrate that the proposed scheme will be a promising solution for the next generation access networks.

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