A self-protected colorless WDM-PON with 2.5 Gb/s upstream signal based on RSOA

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Abstract: In this investigation, we propose and demonstrate a colorless wavelength division multiplexed passive optical network (WDM-PON) at 2.5 Gb/s using reflective semiconductor optical amplifier (RSOA)-based optical networking units (ONUs); together with a self-protected architecture against fiber fault. In the optical line terminal (OLT), we use an array of self-seeding Fabry-Perot laser diodes (FP-LDs) to provide single-longitudinal-mode (SLM) continuous wave (CW) optical sources for the external injection to the RSOA-based ONUs. The self-survivable function for protecting the fiber fault in the distributed fibers and the proposed network performance are investigated and discussed.

OCIS codes: (060.2320) Fiber optics communications; (060.4257) Networks, network survivable.

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1. Introduction

WDM-PON has attracted much attention in recent years as an enabling technology for the fiber to the home (FTTH) to provide high quality data services with guaranteed large bandwidth for end users [1]. For the practical implementation of WDM-PONs, the most critical issue is how to realize low cost transmitters at the subscriber ends [2], and even at the OLT. Among different transmitter architectures, the recently proposed scheme based on broadband spectrum-sliced light-injected FP-LDs is very desirable. This can provide a single low-cost WDM laser source, which is widely tunable (or colorless) [3]. RSOA based WDM-PONs have also been proposed [4-9], including the use of distributed feedback laser diode (DFB-LD) to provide CW light for the upstream signal [4-6]; and signal remodulation based on gain saturated RSOA [7]. Using high temperature and colorless operation of a RSOA as a high-speed 2.5 Gb/s upstream transmitter in a spectrally sliced WDM-PON was also reported [8]. Furthermore, as per channel data rate keeps on increasing, the network reliability and survivability of such access systems need to be addressed. As a result, several implementations have been proposed and discussed for the protection scheme in WDM-PON to avoid fiber fault [10-12].

In this paper, we propose and demonstrate a simple self-protected configuration for RSOA-based colorless WDM-PON against fiber fault. Here, we use the duplicated fiber in the distributed section between the remote node (RN) and the ONUs; together with a 1x2 optical switch (OS), which keep monitoring the optical power at the downstream receiver (Rx) for automatic switching. The switching of data traffic from working to protection fiber is controlled by the ONU itself, and the centralized protection control at OLT is not required. In addition, based on the array of self-seeding FP-LDs to serve as the WDM CW injected wavelengths, the RSOA-based upstream signal on each ONU can be modulated up to 2.5 Gb/s. The performance of the proposed CW laser and the proposed PON system have been also investigated and discussed.

2. Experiments and results

An experimental setup of the proposed self-protected RSOA-based colorless WDM-PON using CW external injection is illustrated in Fig. 1. The proposed WDM CW injection lasers are consisted of N FP-LDs, $2\times N$ arrayed waveguide grating (AWG), N polarization controllers (PCs), and a fiber mirror (FM). Each ONU is constructed by a 1×2 OS, a C/L band WDM coupler (WC), a C-band RSOA, and an L-band Rx. In the RN, each output port of the $1\times N$ AWG connects to a 1×2 dB optical coupler (CP) to split the optical power into two paths, which represent the working and protecting fibers for the fiber network, respectively. And the two fiber paths are connected to the OS on each ONU. Bidirectional erbium-doped fiber amplifier (EDFA) is used to compensate the insertion losses in the access system and amplify the CW injection lights. In the experimental demonstration, the bidirectional EDFAs are constructed by using two C-band EDFAs (gain=25dB, noise figure=5dB, output saturated power=15dBm) in opposite directions and two optical circulators.

First, we describe the proposed self-protected WDM-PON scheme. In Fig. 1, the black (solid line) and blue (dash line) fibers represent the working and protection fibers respectively. Initially, all the OSs in each ONUs are located at point “1” when there is no fiber fault. In each ONU, the connection of working or protection fiber is determined by the OS, which is controlled by an electronic driving circuit, which keeps monitoring the received optical power at the downstream Rx inside the ONU. If there is a fiber cut on the distributed fiber branch “*i*”

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in WDM-PON, the data traffic will be unreachable from OLT to ONU$_i$, as shown in Fig. 2. Then the Rx does not detect any signal from the OLT, and the OS will automatically switch to the protection fiber. The switching characteristic of OS in this experiment is shown in Fig. 3, showing the protection switching time of the OS is measured within in 100 ms. The proposed protection can simplify the restoring mechanism and reduce the processing load on OLT, since the switching is controlled by the ONU itself, and the centralized protection control at OLT is not required.

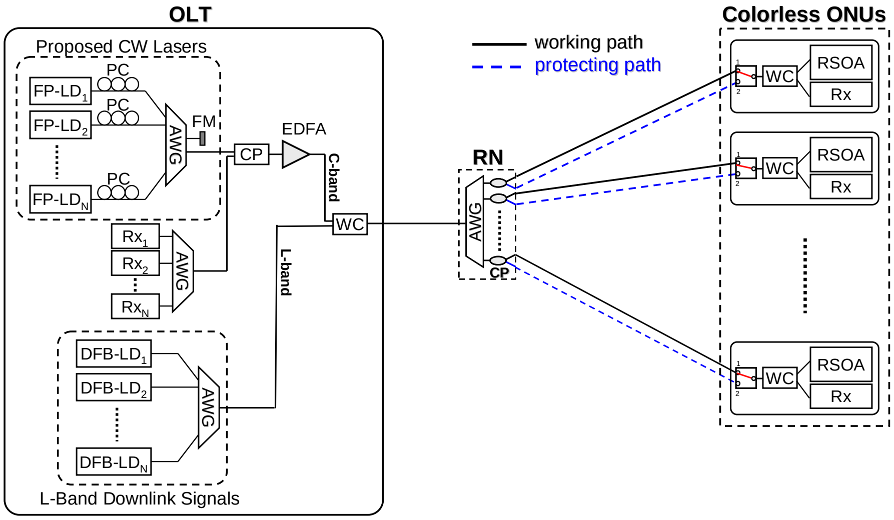

Fig. 1. Experimental setup uses self-seeding Fabry-Perot lasers to serve as CW WDM external injection into each ONU for self-protected RSOA-based colorless WDM-PON, when the access system is without any fiber fault.

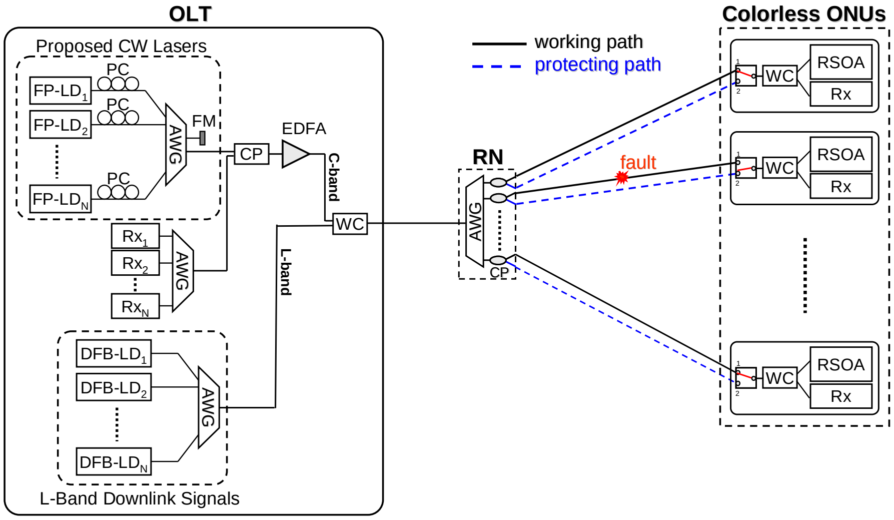

Fig. 2. Proposed self-protected RSOA-based colorless WDM-PON when a fiber fault occurs between RN and ONU$_2$ in working fiber.

Next, the detailed operation of the proposed CW laser in the OLT using self-seeding FP-LD is described. As illustrated in Fig. 1, the threshold current (I_{thres}) and mode spacing ($\Delta\lambda$) of the multi-longitudinal-mode (MLM) FP-LD are about 9.5 mA and 1.38 nm, respectively. The FP-LD has ~45% front-facet reflectivity (commercially available). The PC is used to control the polarization state to maintain the output wavelength and stabilize the power. The FM has ~99% reflection in C band operating range. The MLM FP-LD is used to align the corresponding filter mode of the AWG used in the OLT. Then, the filtered light could pass through the AWG and reflect back to the FP-LD by the FM. The FP-LD would lase a CW light due to self-seeding. As a result, we can employ the array of FP-LDs to retrieve the CW SLM multi-wavelength source. The self-seeding FP-LD can be achieved by using fiber Bragg grating to provide the back-reflected optical signal [13]. Here, we use the AWG and the FM, which acts as a wide-band reflector to simultaneously injection-seed several FP-LDs. Finally, the CW SLM WDM wavelengths are used to inject into RSOAs in each ONUs for upstream signals. In the experiment, a 1.38 nm mode spacing FP-LD are used for generating CW wavelength. Thus, we believe that 21 CW lasing wavelengths can be retrieved in the effectively operating range of 1530 to 1560 nm (C-band).

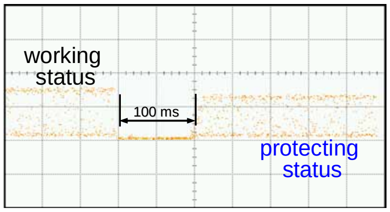

Fig. 3. Protection switching time measurement for the self-protected system.

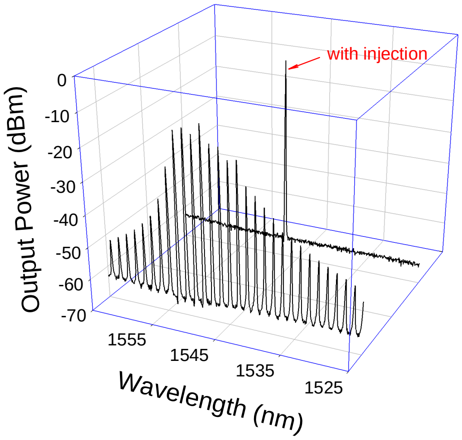

Fig. 4. The output spectra of MLM FP-LD and SLM FP-LD without and with self-seeding.

To observe and measure the output wavelength and power of the proposed CW lasers, an optical spectrum analyzer with a 0.01 nm resolution is used in the experiment. Figure 4 shows the output spectra of the free-run MLM FP-LD and SLM FP-LD at lasing wavelength 1540.5 nm after self-seeding when the bias current and temperature are at 25 mA and 20 ^{o}C, respectively. For the proposed laser scheme, the output power and the side-mode suppression ratio (SMSR) of the lasing wavelength can achieve –8 dBm and 52 dB. To investigate the stability of the output power and wavelength, the short-term stability measurement of the proposed CW laser was performed. The lasing wavelength was measured in observation time over 30 minutes. Figure 5 shows that the proposed self-seeding laser has a small wavelength

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variation of 0.02 nm and power fluctuation of 0.7 dB.

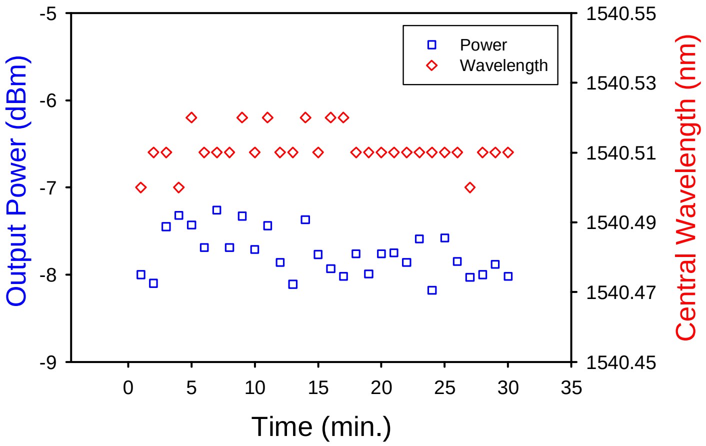

Fig. 5. Output power and wavelength variations of the proposed self-seeding CW laser at 1540.5 nm initially over 30 minutes observation time.

To characterize the issue of temperature fluctuation on the proposed laser scheme, the variations of SMSR, output power, and output wavelength are measured and analyzed at different temperature. Initially, the bias current and temperature of FP-LD is 25 mA and 20 °C. When the temperature is above and below 20 °C, the output power and SMSR of proposed laser decrease gradually, as shown in Fig. 6. In the operating temperature range (14-28 °C), the maximum variations of output power, output wavelength and SMSR are 8.6 dB, 0.9 nm and 12.7 dB, respectively.

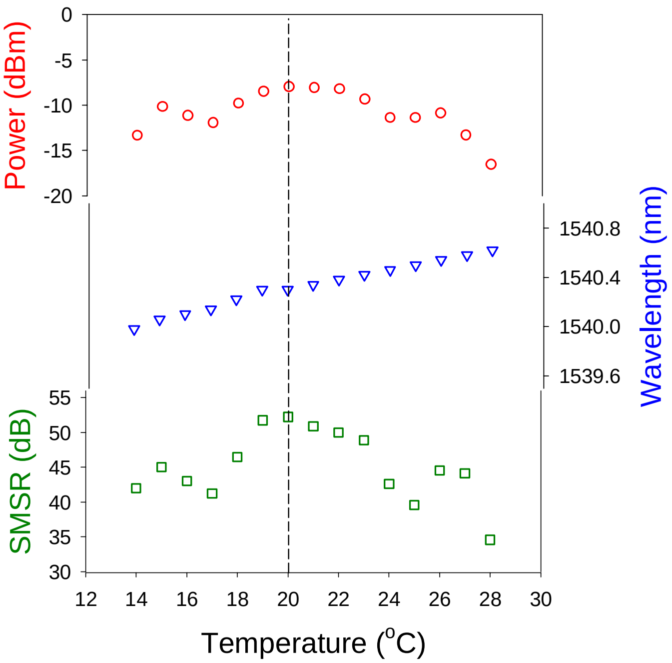

Fig. 6. Output power, output wavelength and SMSR of the proposed CW laser source under the temperature variation of FP-LD from 14 to 28 °C. Initially, the temperature of FP-LD is set at 20 °C.

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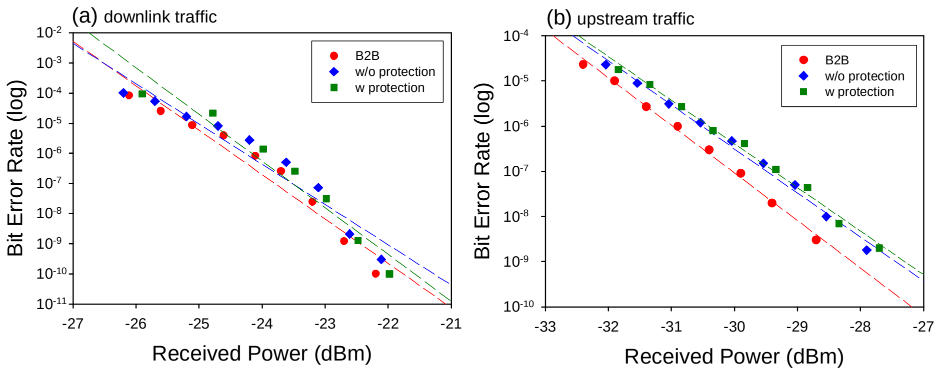

Fig. 7. BER for the (a) downstream and (b) upstream traffic with and without protection.

The 1540.5 nm CW wavelength generated by the proposed self-seeding FP-LD in OLT will be amplified by the EDFA and then injected into the RSOA (*model SOA-RL-OEC-1550 of CIP Ltd*.) in the ONU after passing through 20 km standard single-mode fiber (SSMF). The bias current of the RSOA is 80 mA with 17 dB gain; and the polarization dependent gain (PDG) is smaller than 1 dB. The injected wavelength will be amplified by the RSOA to serve as the upstream wavelength (λ_{up}). And the DFB-LD in the OLT is set at 1560.4 nm for downstream signal (λ_{down}). The upstream signal is generated by directly modulated the RSOA with a 2.5 Gb/s non-return-to-zero (NRZ) $2^7–1$ pseudo random binary sequence (PRBS) data, using driving voltages of 5.2 $V_{peak\text{-}peak}$. The downstream signal is generated by external modulation using lithium niobate intensity modulator to produce a 10 Gb/s NRZ signal. The output powers of the DFB-LD and RSOA-based transmitter are 3 dBm and –5.4 dBm respectively. We use PIN at the ONU and APD at the OLT. The bit error rate (BER) curves for the downstream and upstream traffic with and without protection are shown in Figs. 7(a) and 7(b), respectively. The power penalties of downstream and upstream traffics are below 0.4 and 0.7 dB respectively at BER of 10^{-9}, successfully demonstrating the feasibility for the proposed colorless self-protected WDM-PON with simple architecture.

3. Conclusion

We proposed and experimental demonstrated a colorless WDM-PON with 2.5 Gb/s RSOA-based upstream signal with self-protected architecture against fiber fault. Besides, using an array of self-seeding FP-LDs can retrieve WDM SLM CW light sources to serve as an external injection into the RSOA-based ONUs for generating the upstream traffic up to 2.5 Gb/s. A simple self-protection architecture using duplicated fibers in the distributed section; together with an OS was proposed and demonstrated. The switching of data traffic from working to protection fiber is controlled by the ONU itself, and the centralized protection control at OLT is not required.

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