A Survivable Protection and Restoration Scheme using Wavelength Switching of Integrated Tunable Optical Transmitter for High Throughput WDM-PON System

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Abstract: A survivable protection and restoration mechanism is proposed using wavelength switching of low-cost integrated tunable laser assembly to protect multiple fiber failures in a high capacity colorless WDM-PON. This scheme does not require any expensive and complex opto-electronic space switching device for high throughput WDM-PON system.
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1. Introduction

The Wavelength division multiplexed passive optical network (WDM-PON) is being considered as the ultimate solution to meet the ever increasing bandwidth demand with high quality of services (QoS) for the next-generation broadband access systems [1]. The WDM-PON incorporated with centrally managed colorless optical network units (ONUs) is the most desirable one as it can provide cost-effective and operationally efficient access to the end users. Realization of colorless, self-reflective ONU for future WDM-PON are already demonstrated by various research groups exploiting reflective semiconductor optical amplifier (RSOA) [2-3], injection-locked Febry-Perot laser diode (FP-LD) [4] and reflective electro-absorption modulator (R-EAM) [5]. Nonetheless, those schemes either suffer from limited bandwidth capacity and/or performance degradation because of Rayleigh backscattering and other back reflection from centrally distributed light source for upstream transmission. In this regard, using tunable optical transmitter with narrow optical linewidth and embedded local wavelength locker is an attractive candidate to achieve higher bandwidth capacity of 10Gb/s and beyond on a pre-set wavelength in a cost-effective way [6-7]. Besides, thanks to the mature semiconductor laser manufacturing technology, temperature independent integrated tunable laser assembly (ITLA) such as modulated grating Y-branch laser (MG-Y) with wide tuning range and nano-second wavelength switching speed is now commercially available [8]. Using such low cost tunable laser transmitter at the ONU can provide cost-effective solution for high bit rate colorless WDM-PON as well as eliminate other system performance degradations caused by Rayleigh backscattering in centralized light sources.

As per channel data rate in the future WDM-PON access networks are envisioned to 10Gbps or more, the network reliability and survivability of such high-speed networks need to be addressed. Using space-switching for path protection makes the WDM-PON system complex and costly [9-13]. In contrast, a self-survivable optical path protection and restoration using wavelength switching can be realized by using ITLA that can simultaneously provide high bit rate network capacity as well as network survivability in a cost-effective manner. In this paper, we propose a self-survivable, centrally managed, colorless WDM-PON broadband access system that can provide high capacity symmetric data rate of up to 10Gb/s using low-cost MG-Y type ITLA. The self-survivable protection and restoration of both the distribution and feeder fibers is realized by centrally managed wavelength switching technique and without requiring any opto-electronic space switching.

2. System Architecture and Operation Principles

Fig. 1(a) shows the system architecture of the proposed self-survivable WDM-PON using wavelength switching techniques realized by low cost MG-Y type integrated tunable laser assembly (ITLA). Two sets of ITLA are associated for i-th ONU connection - one at CO as downstream transmitter ($ITLA_{id}$) and one at ONU_i as upstream transmitter ($ITLA_{iu}$). The ITLA associated with ONU_i link are assigned to two pre-defined wavelengths - λ_i as working wavelength and $\lambda_{(i \bmod N)+1}$ as protection wavelength, where N is the maximum number of ONUs. Fig. 1(b) shows the wavelength assignment to various ONUs in the normal working mode and protection mode of operation. It is observed that the wavelength $\lambda_{(i \bmod N)+1}$ is assigned to ONUi as protection wavelength, while the same wavelength is assigned to $ONU_{(i \bmod N)+1}$ as normal operational wavelength. The output from the ITLAs are connected to the feeder and distribution fibers using four sets of Arrayed waveguide grating (AWG) filters at the CO and RN as shown in Fig 1(a). The port assignment of AWG_1, AWG_2, AWG_3 and AWG_4 to the ITLAs guarantee the appropriate selection of working or protection wavelength to the associated feeder and distribution fibers.

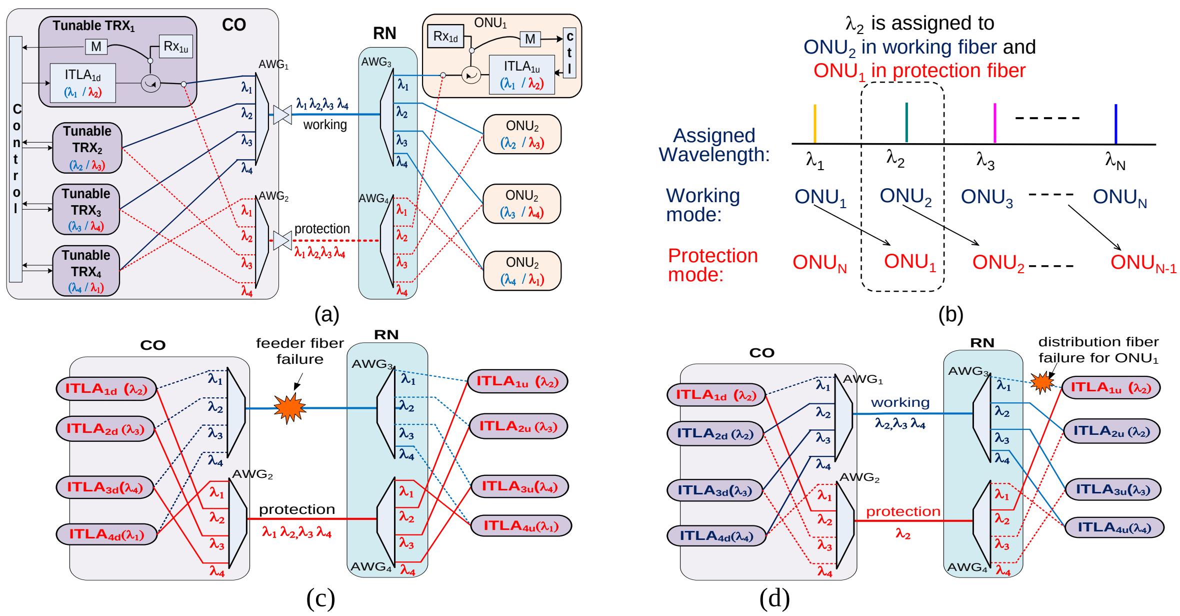

Fig. 1. Self-survivable WDM-PON using wavelength switching of low cost ITLA (a) Schematic of the proposed self-survivable WDM-PON (b) Wavelength assignment for various ONUs in working and protection mode. (c) Feeder fiber failure (d) Distribution fiber failure.

A. Normal Working Mode: In the normal working operational mode, the ITLAs of ONU_1, ONU_2, ONU_3, ONU_4 for upstream and downstream signals are tuned to the respective assigned wavelength at λ_1, λ_2, λ_3 and λ_4 as shown in Fig 1 (a). All the wavelength channels are transmitted through the working feeder and distribution fibers through AWG_1 and AWG_3 at the CO and the remote node (RN).

B. Failure Protection Mode: Any signal loss because of the feeder and distribution fiber failure are detected by the power monitor M at the CO and ONU and immediately perform the wavelength switching of the associated $ITLA_{id}$ and $ITLA_{iu}$ to the pre-assigned protection wavelength state. The corresponding ONU is then served by the protection wavelength through protection feeder and distribution fibers via AWG_2 and AWG_4 at the CO and RN, respectively. The selection of working or protection mode of one ONU is completely independent of the operating mode of the other ONUs. Fig. 1(c) shows the protection mechanism after failure occurred in the feeder fiber between the CO and RN or the remote node AWG_3. Any one of these failures immediately prompts the wavelength switching to select appropriate protection wavelengths at the respective ITLAs for all ONUs. As shown in Fig.1 (c), the four ONUs are now served by protection wavelength λ_2, λ_3, λ_4 and λ_1, respectively over protection feeder fiber. Similarly, the illustration in Fig.1 (d) shows a scenario when the distribution fiber between the AWG_3 of RN and ONU_1 is cut. In this case, both ONU_1 and ONU_2 are assigned to the same wavelength λ_2, however, one in the working fiber and the other in the protection fiber. Since working and protection wavelengths use two disjoint paths, there is no interference problem of assigning the same wavelength (e.g. λ_2 in this case) for ONU_1 and ONU_2 simultaneously. All other ONUs are served by their respective normal working mode wavelengths.

3. Experimental Setup and Results

Fig. 2 (a) shows the experimental setup of the proposed self-survivable WDM-PON using wavelength switching of the low-cost ITLA transmitter. The ATLS7600 ITLA is based on monolithic InP chip that integrates a tunable Modulated Grating Y-branch (MG-Y) laser with a semiconductor optical amplifier (SOA). The laser is electronically tunable over C-band with 50GHz ITU-T channel spacing and exhibit up to 13 dBm output power, 5MHz linewidth and over 40 dB side-mode suppression ratio. The integral wavelength locker allows channel stabilization to within ±2.5 GHz. At the CO, the continuous wave (CW) output of the ITLA is injected into a Mach-Zehnder type intensity modulator (IM). The IM is driven by 10Gb/s downstream (DS) data from a PRBS generator with PRBS length of (2^{31}-1). The output of the IM is optically amplified and fed into the working and protection fibers using optical circulator, optical splitter and four 100GHz spaced array waveguide grating filters. Another set of ITLA and IM is used at the ONU for upstream (US) signal generation. The wavelength of the both ITLAs is set to 1556.32nm and 1557.12 nm for working and protection mode, respectively, as shown in the inset of Fig 2(a). The ITLAs are controlled from two computer terminals via RS232 communication. Fig. 2(b) shows the wavelength switching characteristics after a fiber failure occurred. We used commercially available 10Gbps PIN receiver to

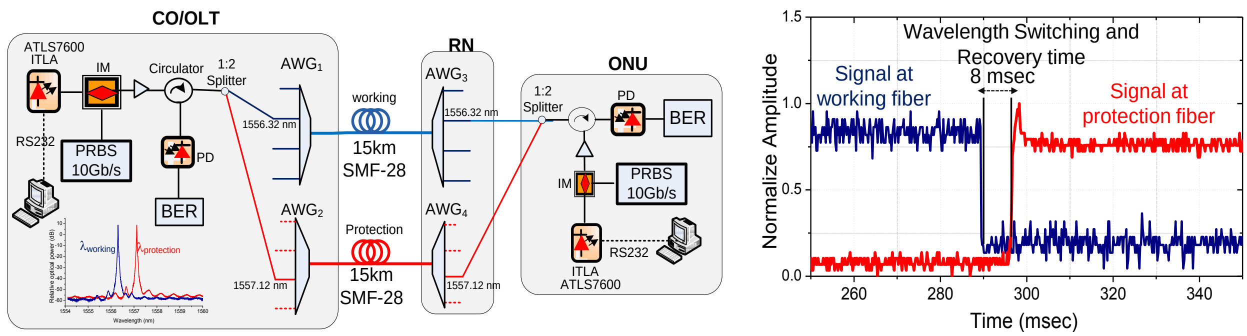

Fig. 2 (a) Experimental setup of the proposed self-survivable WDM-PON using wavelength switching of low-cost ITLA (b) Wavelength switching and recovery time measurements.

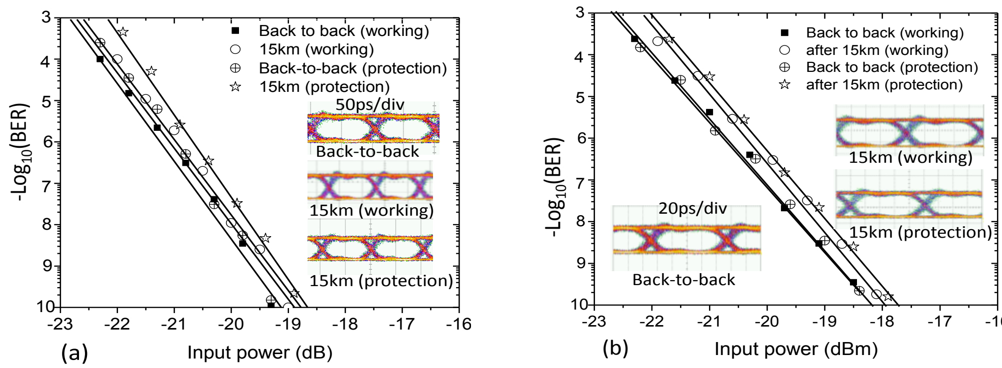

Fig. 3. BER measurements and optical Eye diagrams of (a) downstream (b) upstream signals both at working and protection mode

receive both DS and US data at the ONU and CO. Fig. 3 shows the bit-error-rate (BER) and the eye diagrams of the DS and US signals. The eyes are wide open with good extinction ratio. At 10^{-10} BER, the power penalty of the 10Gbps DS and US channel is less of 0.5dB after 15km SMF-28 transmission both in working and protection mode. The power penalties are mainly due to the fiber chromatic dispersion and cascaded filtering effects at CO, RN and ONU and unwanted reflections at the circulators.

4. Conclusion

We proposed a self-protected colorless WDM-PON system employing low-cost MG-Y type tunable optical transmitter at the CO and ONU that can simultaneously provide high network capacity, network survivability as well as eliminate transmission impairment caused by Rayleigh backscattering in centralized light sources. The self-survivable protection-restoration mechanism is realized by wavelength switching of the tunable optical transmitter in order to protect the WDM-PON system from suffering multiple faults such as feeder fiber failure, distribution fiber failure and remote node failure. This scheme does not require any expensive and complex opto-electronic space switching devices. The experimental results show that error-free transmissions of both 10-Gbps DS and US have been achieved with less than 0.5dB both in working and protection mode after 15-km SMF-28 transmission.

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