An Optical Switch-Based Self-Restored WDM-PON Architecture against Fiber Faults

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ABSTRACT

In this paper, we propose and experimentally demonstrate a simple self-restored architecture for WDM passive optical network (PON) by only adding a novel 2×2 optical switch design in each optical networking unit (ONU). By using the proposed protection architecture, the affected traffic will be restored immediately against fiber fault in the feeder and distributed fibers. Moreover, the performance of proposed self-survivable WDM-PON is also discussed and analyzed.

Keywords: WDM-PON, Self-Protection, Fiber-Fault, Optical Switch

1. INTRODUCTION

Recently, wavelength-division-multiplexed passive optical networks (WDM-PONs) have been extensively studied for last mile applications due to the characteristics of high speed and huge capacity [1], [2]. When a fiber link from the remote node (RN) to one optical networking unit (ONU) is broken in tree-topology WDM-PON architecture, the data traffic from the central office (CO) will be unable to reach the affected ONU. So, the fiber fault protection was one of the critical issues in WDM-PONs. Thus, reliable and survivable access network systems are highly desirable. As data rates in the future WDM-PON access networks are envisioned to reach 10 Gb/s, network reliability and survivability of such networks need to be carefully addressed. The ITU-T G.983.1 on time-division-multiplexed PONs (TDM-PONs) has proposed several PON protection scenarios [3]; however, they are mainly based on duplicating the fibers, ONUs and even the optical line terminals (OLTs). This may greatly increase the cost of the cost-sensitive access networks. Several network architectures have also been reported to realize protection and restoration functions for WDM-PON systems [4]-[6].

In this study, we propose and experimentally demonstrate a self-restored WDM-PON against fiber fault. The proposed protection architecture is formed by only adding a 2×2 optical switch (OS) in each ONU. The data traffic in both downstream and upstream can be automatically re-routed in a pair of ONU while a fiber fault occurs between the RN and ONU. Here, the fault on feeder fiber is also protected by using dual feeder fibers. Moreover, the performance of the proposed self-survivable WDM-PON has been discussed and analyzed.

2. EXPERIMENT AND DISCUSSION

Fig. 1 shows the proposed self-survivable WDM-PON architecture with N pairs of ONUs. In the CO, a 3-port optical circulator (OC) is used to separate the upstream and downstream signals, and a 1×2 optical switch (OS) is used to connect the RN by two feeder fibers for working and protecting statuses. The RN consists of a 2×N WDM array waveguide grating (AWG) and N 1×2 couplers. Every two adjacent ONUs are assigned to act as a group. Each pair of ONUs is connected to the corresponding output port of the AWG via a 1×2 and 50:50 optical coupler, as seen in Fig. 1. In order to support the set of wavelength channels in each ONU group, we utilize the spectral periodic property of AWG; and the proposed wavelength assignment for the downstream and upstream channels are shown in Fig. 2. The downstream wavelengths (A_i, B_i) and the upstream wavelengths (C_i, D_i) in the i-th ONU group (for i = 1, 2, ..., N) are spaced by one free spectral range (FSR) of the AWG, therefore one port of the AWG can support the four wavelength signals simultaneously for data transmission. Inside each ONU, just prior the band-pass filter, a 2×2 optical switch (produced by *Lightwave Link*, Taiwan) is added for self-restoration. The 2×2 OS in the same ONU group is connected with port "2" and "4" by two protecting fibers. A blue band-pass filter is incorporated in ONU_i to filter the downstream

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A_i and the upstream C_i wavelength channels, and a red band-pass filter in ONU'$_i$ is used to filter the downstream B_i and upstream D_i wavelengths.

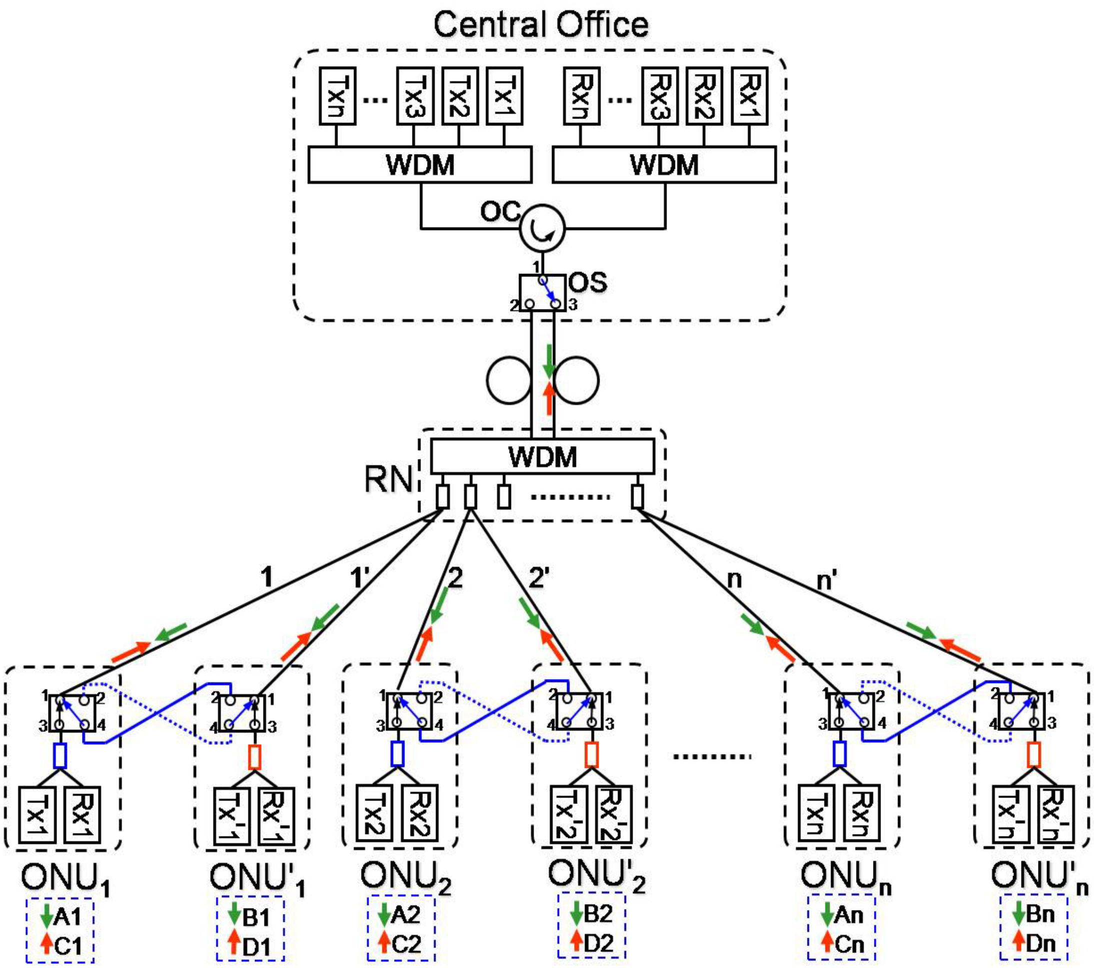

Figure 1. Proposed self-protected WDM-PON architecture against fiber fault.

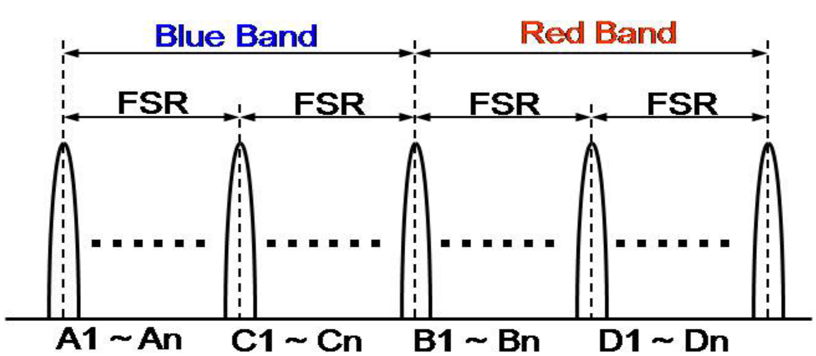

Figure 2. The wavelength assignment plan for the upstream and downstream signals in WDM-PON system.

Then, we discuss the two scenarios of fiber fault. There are two occurrences of fiber faults, one in the feeder fiber (between CO and RN) and the other in the distribution fiber (between RN and ONU). In normal operation, as seen in Fig. 1, the OS in the CO connects the port "1" and "3" for working path and the port "1" and "2" for protecting path. For the 2×2 OS in each ONU, the port "3" and "4" both connect to port "1" in normal status. Here, the protecting fiber between the ONU pair is disconnected in normal working status.

When a fiber fault occurs in the working path between the RN and CO, the entire upstream signals cannot be detected in the CO. Then, the monitor circuit (MC) in the CO will detect a drastic power drop. Then, the MC will trigger the OS to switch the port "3" to "2" in the protecting path for reconnecting the data traffic, as shown in Fig. 3. When the fault is restored, the original working fiber can be regarded as the protecting fiber against fiber fault.

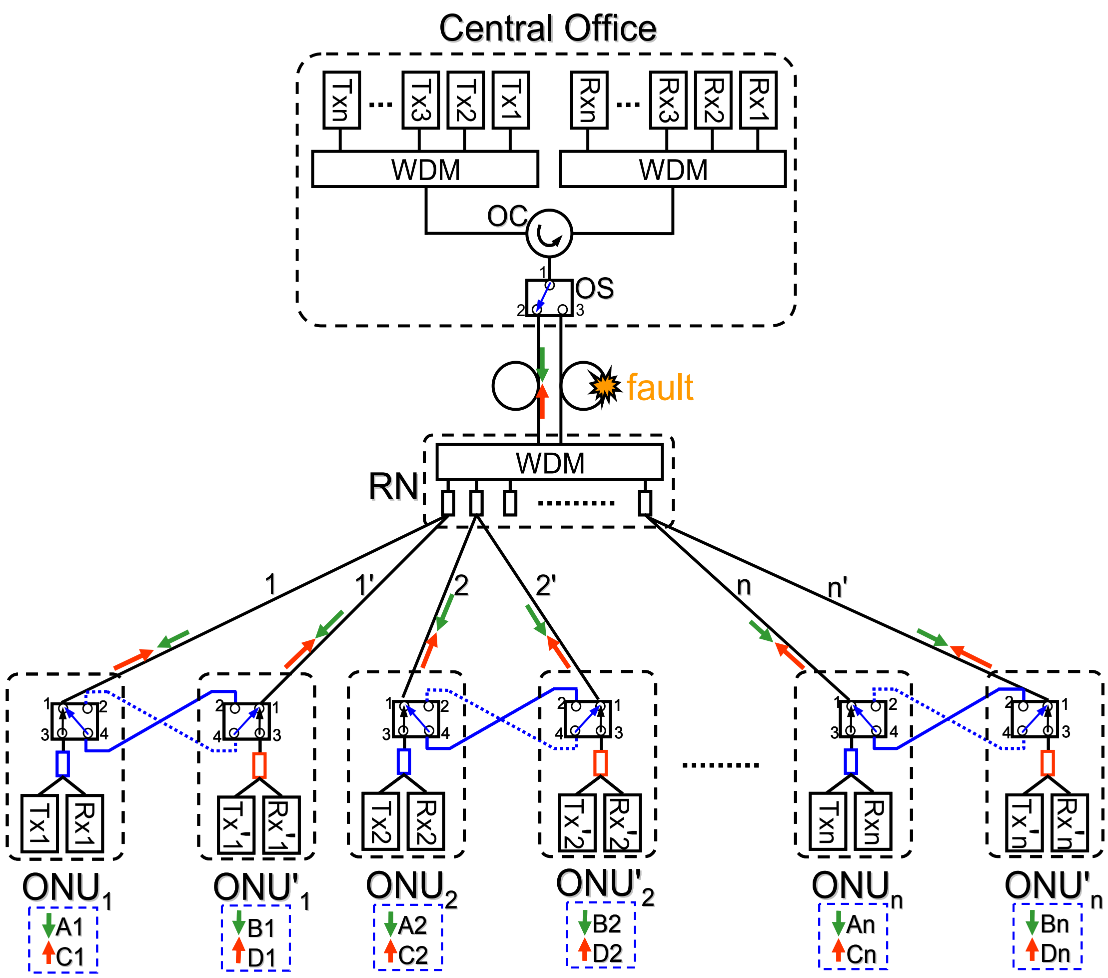

Figure 3. A fiber fault occurs on feeder fiber in the proposed PON system.

Then we discuss the case when fiber fault occurs at the distribution fiber. In normal operation, as seen in Fig. 1, For the 2×2 OS in each ONU, the port "3" and "4" both connect to port "1" in normal status. Here, the protecting fiber between the ONU pair is disconnected in normal working status. Fig. 4 illustrates an ONU pair configuration under a fiber fault between the RN and the ONU_1. The downstream signal (A_1) will not be detected at ONU_1. Thus, the OS direction of ONU_1 will be automatically reconfigured from port "1" to "3" to port "2" to "3", as shown in Fig. 4. Both the upstream and downstream wavelengths of the ONU_1 will be routed to the adjacent ONU'_1 via the protecting fiber, as also shown in Fig. 4. Thus, with this protection mechanism, a fast restoration of fiber fault can be achieved without any disturbance on the existing traffic connection. When the fault is restored, the OS of ONU_1 would switch to the port "1" and "3". Therefore, while a fault is between RN and ONU'_1, the data traffic of ONU'_1 could be also routed to the ONU_1 via the protecting fiber for data reconnection.

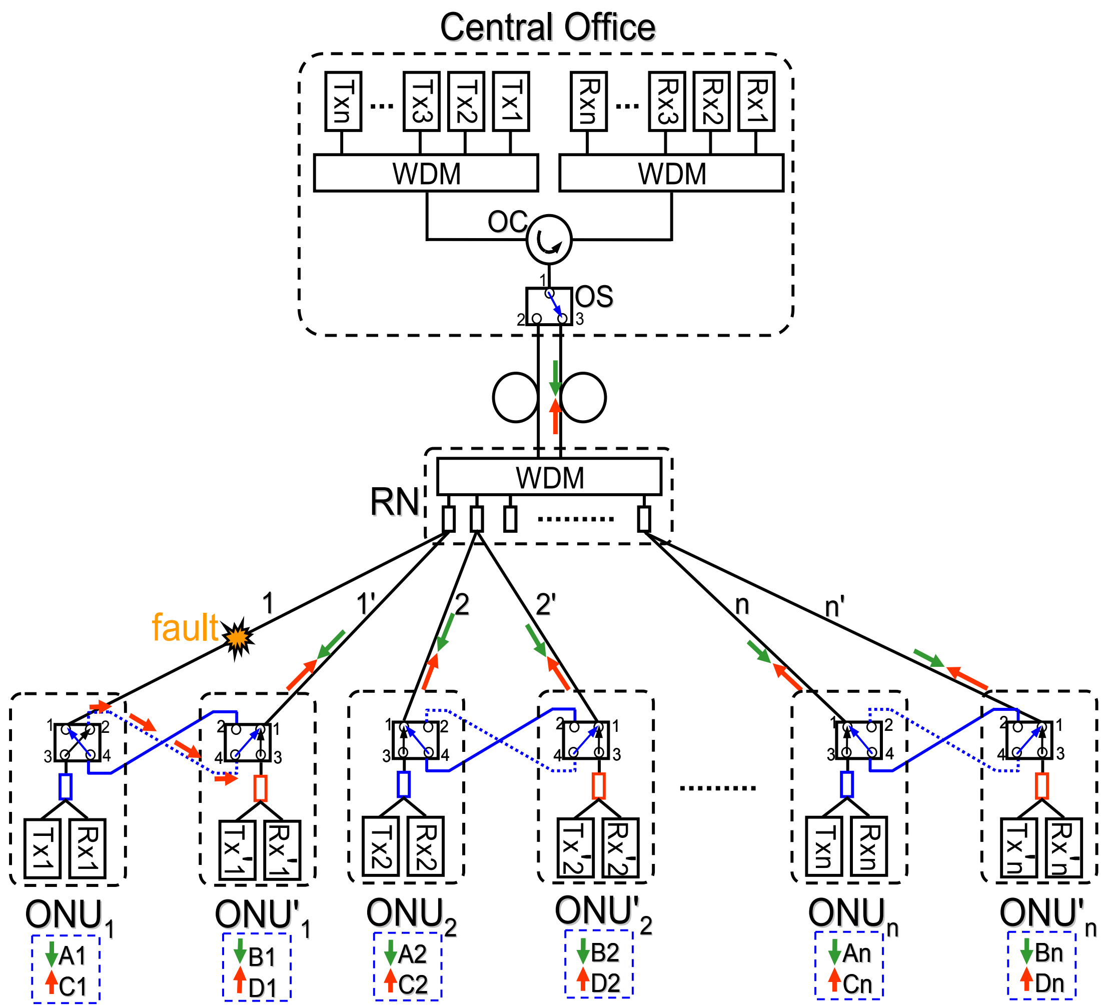

Figure 4. The network protection scheme when the fiber link is broken between RN and ONU1.

In order to investigate the transmission performance of our proposed self-restored PON system, we selected four wavelengths to emulate the downstream and upstream channels for the CO and a pair of ONU_1 and ONU'_1. In this experiment, the A_1 and B_1 with wavelength of 1540.5 nm and 1559.7 nm were served as the downstream wavelengths for ONU_1 and ONU'_1, respectively. The C_1 and D_1 with wavelength of 1541.7 nm and 1560.9 nm were served as the upstream wavelengths for ONU_1 and ONU'_1, respectively. In regard to the power budget of proposed access network, the signal transmits through two OSs (loss of ~0.5 dB), two AWGs (loss of 5 dB), a blue/red filter (loss of 1 dB), a coupler (loss of 3 dB), a circulator (loss of 0.5 dB) and about 27 km single-mode fiber (SMF) (0.2 dB/km at 1550 nm), thus, the total loss budget is less than 22 dB.

In the measurement, each traffic signal was modulated at 10 Gb/s non-return-to-zero (NRZ) format with 2^{31}-1 pseudo random binary sequence (PRBS) data via a $LiNbO_3$ intensity modulation (IM). And the four signals transmitted through the 25 km and 27 km single mode fiber (SMF), respectively, for working and protecting statuses. The bit error rate (BER) performances of downstream and upstream traffic are shown in Fig. 5(a) and 5(b), for the data traffic between CO and ONU_1 and CO and ONU'_1, respectively. Fig. 5(a) shows the BER curves between CO and ONU_1 without and with fault protection. The measured power penalty was less than 0.5 dB at BER of 10-9. Fig. 5(b) shows the observed power penalties between CO and ONU'_1 was about 1.5 dB under BER of 10^{-9}. In addition, we also measured the restoration time of the proposed WDM-PON system. The restoration time of OS was measured within 7 ms, as shown in the inset of Fig. 5(a).

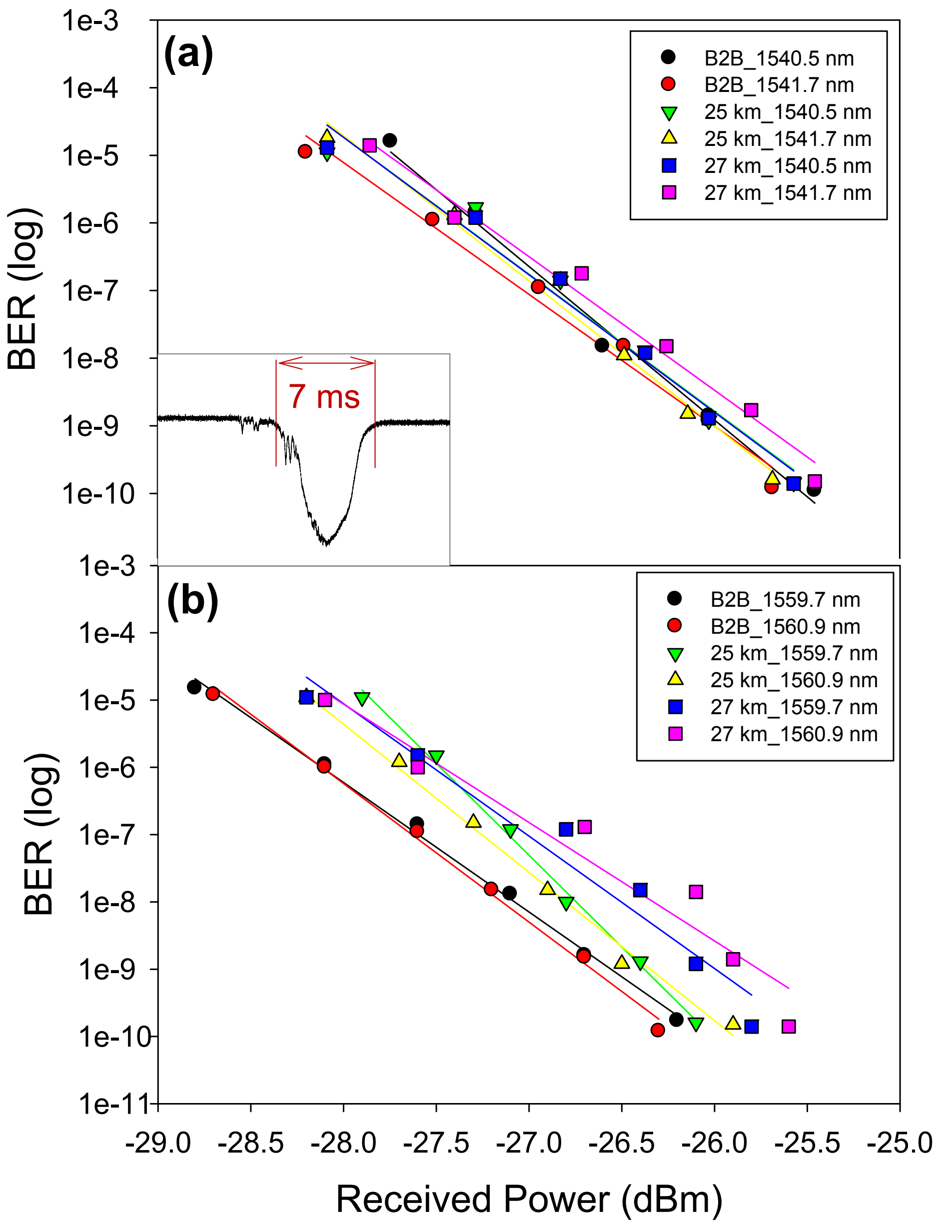

Figure 5. BER performance of downstream and upstream traffic (a) between CO and ONU_1 and (b) between CO and ONU'_1 respectively. The inset of Fig. 5(a) is the switching time of 2×2 optical switch of each ONU.

3. CONCLUSIONS

In summary, we proposed and investigated a self-survivable network architecture for WDM-PON by using a novel 2×2 optical switch design in each ONU. When the fiber cut between the RN and the ONU, the traffic in both downstream and upstream can be automatically rerouted in the ONU pair. Besides, the fault on feeder fiber is also protected by using dual feeder fibers. And the restoration switching time was measured to be about 7 ms. In addition, the protection strategies under two failure scenarios and the transmission performance were also discussed.

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