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Fiber-fault protection WDM-PON using new apparatus in optical networking unit

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ABSTRACT

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

1. Introduction

Recently, wavelength-division-multiplexed passive optical networks (WDM-PONs) have been extensively studied for the last mile applications due to its high speed and huge capacity [1,2]. When the fiber between the central office (CO) and the optical networking unit (ONU) is broken in conventional PONs and WDM-PONs, the data traffic cannot reach the affected ONU, leading to enormous data loss. Hence, fault management is one of the critical issues in PON. As data rate in the future WDM-PON is envisioned to reach 10 Gb/s, network reliability and survivability of such networks need to be carefully addressed. In the ITU-T G.983.1 on time-division-multiplexed PONs (TDM-PONs), several PON protection scenarios have been proposed [3]. However, they are mainly based on duplicating the fibers, ONUs and even the optical line terminals (OLTs). This may greatly increases the cost of the cost-sensitive access networks. Several network architectures have also been reported to realize protection for WDM-PON systems [4–6].

In this paper, we propose and experimentally demonstrate a self-protection WDM-PON against fiber fault. The proposed protection architecture is constructed by adding a 2×2 optical switch (OS) in each ONU. Two adjacent ONUs are interconnected into a group. The data traffic in both downstream and upstream signals can be automatically re-routed in a pair of ONUs when a fiber fault occurs between the remote node (RN) and the ONU. Besides, the fault on the feeder fiber is also protected by using dual feeder fibers. Moreover, the performance of the proposed self-protection WDM-PON has been discussed and analyzed.

Previous protection scheme [6] requires two optical switches (OSs) in each ONU. Unlike the centrally controlled protection scheme [7], our scheme will not influence other normal ONUs in the case of fiber cut. Previous literature [8] also differs from our proposed scheme, since its aim is to achieve a smooth upgrading from TDM-PON to WDM-PON. Furthermore, protection scheme for WDM PON and hybrid WDM–TDM PON [9] has been proposed.

2. Experiments and results

Fig. 1 shows the proposed self-protection 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. A 1×2 optical switch (OS) is used to connect the RN by two feeder fibers for working and protection statuses. The RN consists of a 1×2 coupler, a 1×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 (CP); as shown in Fig. 1. In order to support the set of wavelength channels in each ONU group, we utilize the spectral periodic property of the AWG. The proposed wavelength assignment for the downstream and upstream channels is 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. Initially, two neighboring downstream signals (A_i and B_i) are coupled by a 1×2 blue/red-band WDM coupler (B/R CP) into the i-input port of AWG, as shown in Fig. 1. And, two downstream signals also can be separated in the two

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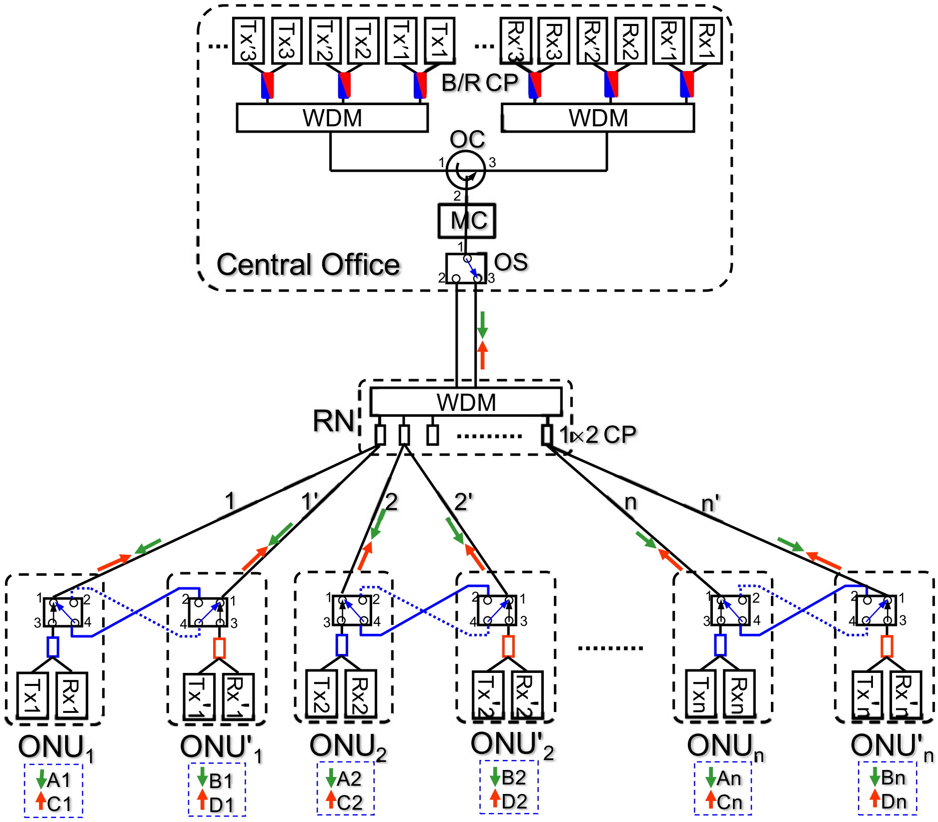

Fig. 1. Proposed self-protected WDM-PON architecture against fiber fault.

adjacent ONUs via the 1×2 red and blue couplers for filtering downstream traffic. As the same, the two adjacent upstream wavelengths are also can be received exactly via the 1×2 B/R CP at the CO, as illustrated in Fig. 1.

Here, inside each ONU, just prior to the 1×2 blue/red coupler, a tailor-made 2×2 optical switch (OS, produced by *Lightwave Link*, *Taiwan*) is added for self-protection. The working principle of the 2×2 OS is described as follows. There is a y-junction waveguide at port 1. Half of the input power will go to port 4 directly, and the other half of the power will be launched into a typical 2×1 OS. The OS has the insertion loss of 0.6 dB, back-reflection of about −45 dB, polarization dependent loss about 0.1 dB, cross-talk about −60 dB and the switching time about 7 ms. The operating wavelength range of OS can be operated between 1520 and 1625 nm. The operating voltage is 5 V and power consumption is 0.2 W. The total insertion loss of the device is about 3.6 dB, and there is no built-in optical amplifier inside the OS. The 2×2 OS in the same ONU group is connected to port "2" and "4" by two protecting fibers. A 1×2 blue coupler is used inside ONU_i to filter the downstream A_i and the upstream C_i

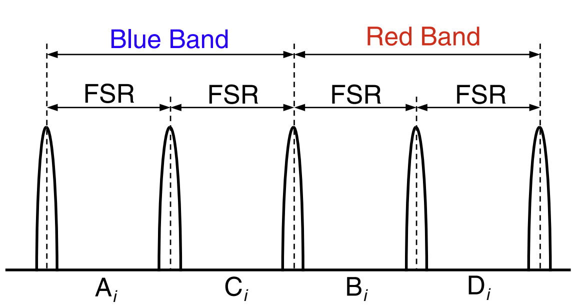

Fig. 2. The wavelength assignment plan for the upstream and downstream signals in WDM-PON system.

wavelength channels, and a 1×2 red coupler in ONU'_i is used to filter the downstream B_i and upstream D_i wavelengths.

Then, we discuss the two scenarios of fiber fault. There are two occurrences of fiber faults, one in the feeder fiber (between the CO and RN) and the other in the distribution fiber (between the RN and ONU). In normal operation, as shown in Fig. 1, the 1×2 OS in the CO connects the ports "1" and "3" for the working path and the ports "1" and "2" for protecting the path. Initially, the direction of 1×2 OS is "1→3" to connect the working fiber path for the downstream and upstream traffic, when there is no fiber fault among the CO and RN, and the RN and each ONU, respectively. And, for the 2×2 OS in each ONU, the ports "3" and "4" both connect to port "1" in normal status for upstream transmission. Thus, the two upstream wavelengths (C_1 and D_1) only can pass through the fibers 1 and 1′, respectively, due to the direction limit of 2×2 OS, as seen in Fig. 1. Furthermore, two adjacent downstream signals (A_1 and B_1) would transmit through the fibers 1 and 1′ (between the RN and ONUs) simultaneously, and then are separated by the 1×2 blue- and red-band couplers.

When a fiber fault occurs in the working fiber path between the RN and CO, all the upstream signals cannot be detected in the CO. Here, the monitor circuit (MC) in the CO will detect a drastic power drop. Then, the MC in the CO will detect a drastic power drop. And, the MC will trigger the OS to switch the ports "3" to "2" (1→2) in the protecting fiber path for reconnecting the data traffic, as shown in Fig. 3. Thus, the MC only is used in CO to monitor and adjust the direction of OS whether detects the upstream powers. If the MC does not detect upstream signal when a fault occurs at a feeder fiber, the MC will switch the direction of OS to 1→2, as seen in Fig. 3.

As a result, if the working feeder fiber is broken, the MC will change the OS state to connect the protecting feeder fiber for signal reconnection. Of course, each ONU also cannot detect the corresponding downstream signal at the same time. Then each ONU will also

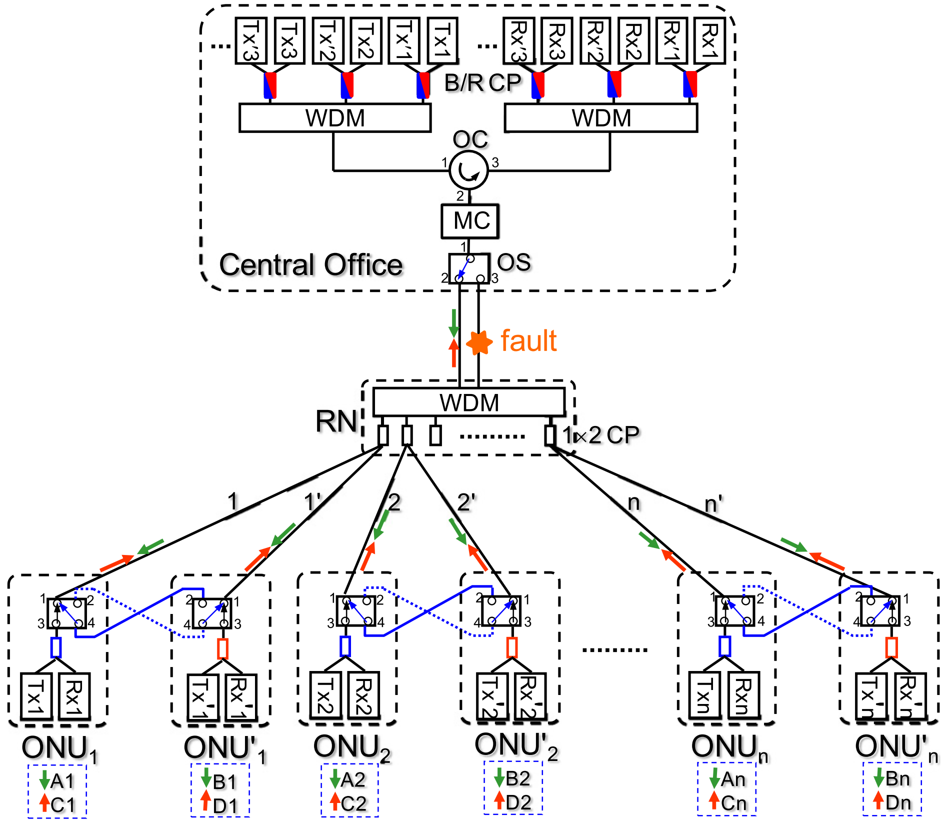

Fig. 3. A fiber fault occurs on feeder fiber in the proposed PON system.

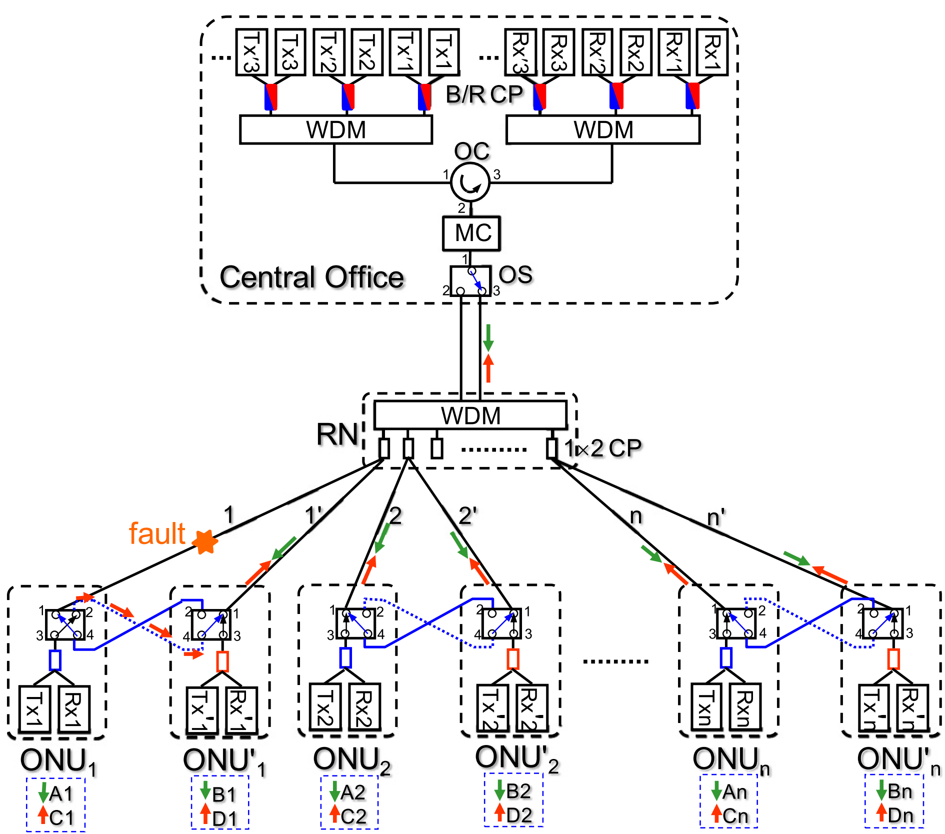

Fig. 4. The network protection scheme when the fiber link is broken between RN and ONU_1.

switch the direction of 2×2 OS (1→3 to 2→3) to connect to the CO via the distribution fiber in the adjacent ONU, as shown in Fig. 1. Here, the direction control of OS in each ONU depends on whether the corresponding downstream signal is detected via the optical receiver (Rx) of each ONU. Even though every ONU is switched to the fiber transmission path, the signal traffic of the entire network also can be maintained, since each ONU is connected to the CO using the distribution fiber of its partner. Therefore, the direction switch of OS in each ONU does not require adding a MC for monitoring the downstream power.

Then, we discuss the case when fiber fault occurs at the distribution fiber. In normal operation, as shown in Fig. 1, for the 2×2 OS in each ONU, the ports "3" and "4" both connect to port "1" in normal status. The protection fiber between the ONU pair is disconnected in normal 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 ports "1" to "3" into ports "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 protection fiber, as also shown in Fig. 4. Thus, with this protection mechanism, a fast restoration of the fiber fault can be achieved without any disturbance on the existing traffic connection. When the fault is restored, the OS of ONU_1 will be switched to ports "1" and "3". On the other hand, 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 protection fiber.

In order to investigate the transmission performance of our proposed self-protection 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 wavelengths 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 wavelengths of 1541.7 nm and 1560.9 nm were served as the upstream wavelengths for ONU_1 and ONU'_1, respectively. Then, we consider the power budget of the proposed access network: the signal transmits through two OSs (losses of ~0.5 dB and ~3.6 dB respectively), two AWGs (loss of 5 dB), a 1×2 blue/red coupler (loss of 3 dB), two couplers (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 29 dB.

In the measurement, each traffic signal was modulated at 10 Gb/s non-return-to-zero (NRZ), $2^{31}-1$ pseudo random binary sequence (PRBS) data via a $LiNbO_3$ intensity modulation (IM). And the four signals were transmitted through the 25 km and 27 km single mode fiber (SMF), respectively, for working and protection statuses. The bit error rate (BER) performances of downstream and upstream signals between CO and ONU_1; and CO and ONU'_1 are shown in Fig. 5(a) and (b), 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 power penalties between CO and ONU'_1. In Fig. 5(b), since the wavelengths (close to L-band) located at one side of the EDFA gain profile, the power penalties between CO and ONU'_1 are larger than that between CO and ONU_1. 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).

3. Conclusion

In summary, we have proposed and investigated a self-protection network architecture for WDM-PON by using a 2×2 optical switch

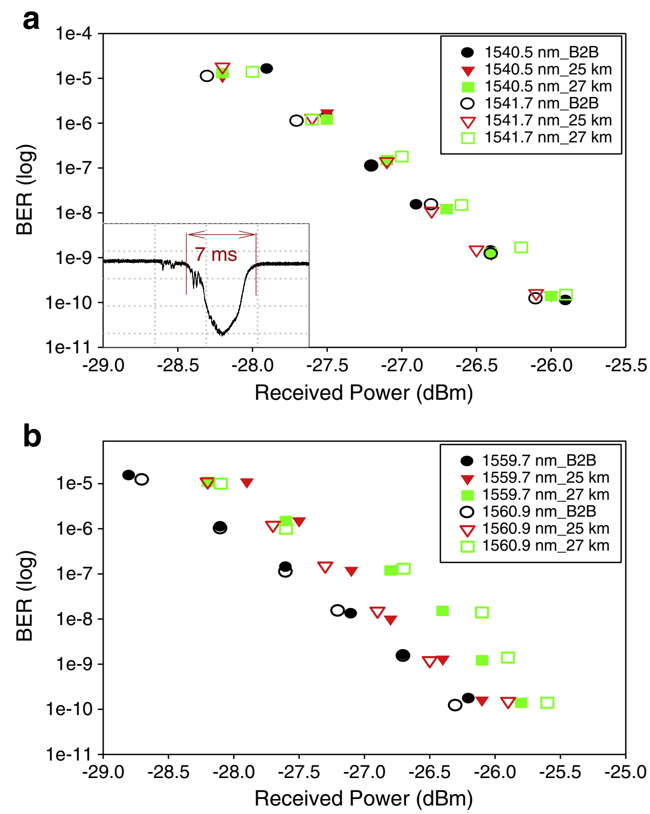

Fig. 5. BER performance of downstream and upstream traffic (a) between CO and ONU_1 and (b) between CO and ONU'_1 respectively. The inset of Fig. 5(a) is the switching time of 2×2 optical switch of each ONU.

(OS) design in each ONU. Two adjacent ONUs are interconnected into a group. When there is a fiber cut between the RN and the ONU, the traffic in both downstream and upstream can be automatically re-routed in the ONU pair. Besides, the fault on feeder fiber is also protected by using dual feeder fibers. And the restoration time was measured to be about 7 ms. The protection strategies under two failure scenarios and the transmission performance were also discussed.

References

[1] G. Talli, P.D. Townsend, Journal of Lightwave Technology 24 (2006) 2827.
[2] R.D. Feldman, E.E. Harstead, S. Jiang, T.H. Wood, M. Zirngibl, Journal of Lightwave Technology 16 (1998) 1546.
[3] Broad-Band Optical Access Systems Based on Passive Optical Networks (PON), ITU-T Recommendation G.983.1, , 1998.
[4] C.H. Yeh, C.W. Chow, C.H. Wang, F.Y. Shih, H.C. Chien, S. Chi, Optics Express 16 (2008) 12296.
[5] X. Sun, C.K. Chan, L.K. Chen, IEEE Photonics Technology Letters 18 (2006) 631.
[6] T.J. Chan, C.K. Chan, L.K. Chen, F. Tong, IEEE Photonics Technology Letters 15 (2003) 1660.
[7] Z.X. Wang, X.F. Sun, C. Lin, C.K. Chan, L.K. Chen, IEEE Photonics Technology Letters 17 (2005) 717.
[8] J. Chen, L. Wosinska, Journal of Optical Networking 6 (2007) 514.
[9] J. Chen, L. Wosinska, S. He, IEEE Photonics Technology Letters 20 (2008) 389.