Self-protection against fiber fault for ring-based power-splitting passive optical networks

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Abstract. We propose and investigate a new ring-based power-splitting passive optical network (PS-PON) with a self-healing mechanism that prevents fiber fault. Using our proposed Y-type passive component with bidirectional function in each remote node (RN), the proposed ring-based PS-PON can be retrieved directly under single fiber failure.

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1 Introduction

Because of the requirements of high capacity data access and multiservices (such as Internet, video, voice, etc.), fiber to the home (FTTH) in optical access networks is getting more and more important.[1] Fiber-based access networks would provide the greatest high-speed bandwidth for downstream and upstream data connections. Therefore, power-splitting passive optical networks (PS-PONs) are the choices for FTTH network applications. Recently, PS-PONs have been thoroughly explored and standardized[2–4] for point-to-multipoint solutions moving into the access field. The broadband PON (B-PON) standard has already existed.[2] In addition, the standards in gigabit PON (G-PON) as well as for Ethernet PON (E-PON) are emerging. Generally, the architectures of PON have three basic topologies of bus, star, and ring structure, respectively. The point-to-multipoint connectivity between the optical line termination (OLT) and each optical network unit (ONU) would be achieved by employing a passive splitting device on the remote node (RN). Traffic from an OLT to an ONU is called "downstream" (point-to-multipoint), and traffic from an ONU to the OLT is called "upstream" (multipoint-to-point). Two wavelengths of 1310 and 1490 nm are used for the upstream (λ_{up}) and downstream (λ_{down}) transmissions, respectively. While a fiber link from the OLT to the ONU is cut due to some reason, the affected ONU will become unreachable from OLT. Furthermore, to achieve fiber network protection, the alternative protection fiber paths should be completed.[2,5,6]

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We have proposed and demonstrated a novel self-protecting architecture for a ring-based PON to prevent fiber failure. The proposed configuration not only can provide a protection mechanism, but also can obtain the approximate fiber-fault point in the major ring path immediately by OLT. In addition, the downstream traffic performance has also been measured and discussed in this ring-based access network.

2 Proposed Architecture

Figure 1(a) shows the traditional ring-based architecture in TDM-PONs. The entire data path from OLT to ONU in Fig. 1(a) only uses one direction for the downstream and upstream traffics without any fiber fault protection. A 1×2 optical splitter (coupler, CPR) is used in RN to connect each ONU for data link, as shown in Fig. 1(b). However, when a fiber fault occurs at the "F" point in the fiber ring path, this access network does not have any function behind the failure point. Thus, the upstream signal from ONU after this fault point is unable to advance. To achieve a desired network survivability, different protection schemes are recommended. The dual-path technique with double transceivers (line terminals, LTs) at both ends and two individual physical paths for the self-protecting ring-based or tree-based PS-PONs has been studied.[2,6] Furthermore, the two paths increase the cost of building fiber and need to add other passive components. An additional transceiver in OLT and ONU also increases the cost in PONs. To improve

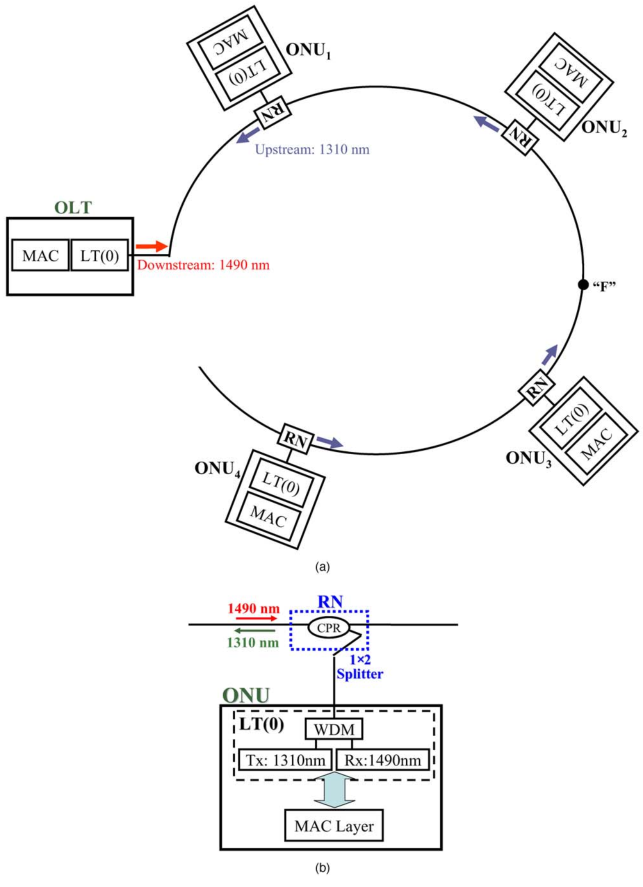


Fig. 1 (a) Traditional ring-topology PON with four ONUs. (b) The 1×2 optical splitter in RN to connect each ONU.

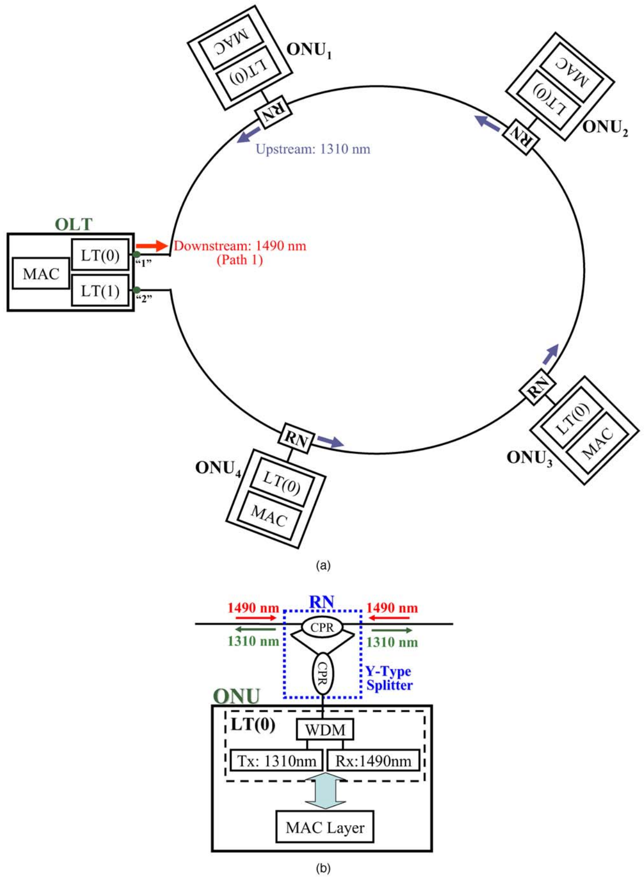


Fig. 2 (a) The proposed self-protecting ring-based PON with four ONUs without any fiber fault occurring (OLT has two transceivers). (b) The proposed Y-type optical splitter with bidirectional function.

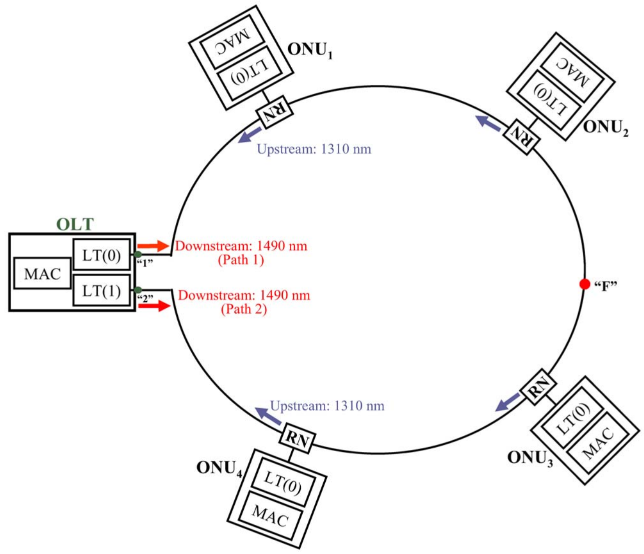


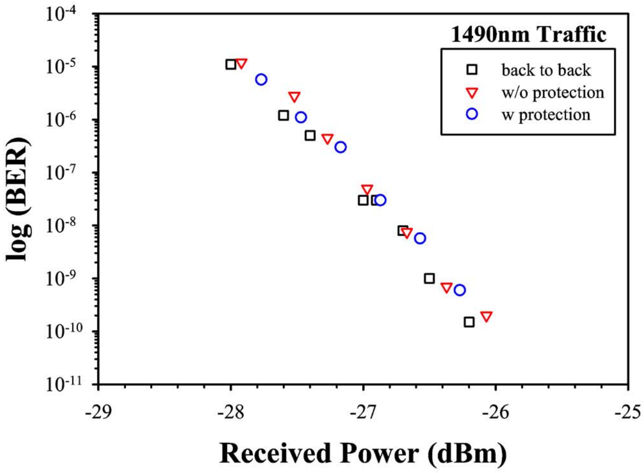
Fig. 3 The proposed self-protecting ring-based PON while a fiber fault occurs at the "F" point. LT(0) still operates to serve ONU_1 and ONU_2, and LT(1) will be started immediately to serve the remaining ONUs.

these drawbacks, we have proposed and investigated a new ring-based architecture with a self-protecting function in PON only by one fiber path, as shown in Fig. 2(a). In the proposed architecture, we use two line terminals [LT(0) and LT(1)] (also called optical transceivers) in OLT for the downstream and upstream data links. LT(0) and LT(1) connect the points "1" and "2" for data link in the same ring path, respectively. In normal status, the LT(1) is static without any action. The LT(0) transmits a downstream signal through path 1 (clockwise) without any fiber fault, and LT(1) is prepared against the failure occurring. Moreover, Fig. 2(b) presents the proposed Y-type optical splitter in RN with bidirectional function to access the downstream and upstream links. This Y-type splitter is constructed by 1×2 and 2×2 optical couplers. The two couplers are combined to act as a bidirectional optical splitter for two direction data links. The proposed Y-type component only increases the power-loss budget of 3 dB in each RN. When a fiber fault occurs at the "F" point in Fig. 3, the ONUs behind the fault point is unreachable. LT(1) is started by the same media access control (MAC) in OLT for data traffic through path 2 (counterclockwise) to serve the remaining ONUs at the same time. Moreover, the fault point was also located between ONU_2 to ONU_3, because the upstream link behind ONU_2 cannot be received by OLT, as diagramed in Fig. 3. When failure is restored, then the operation mechanism of PON will revive.

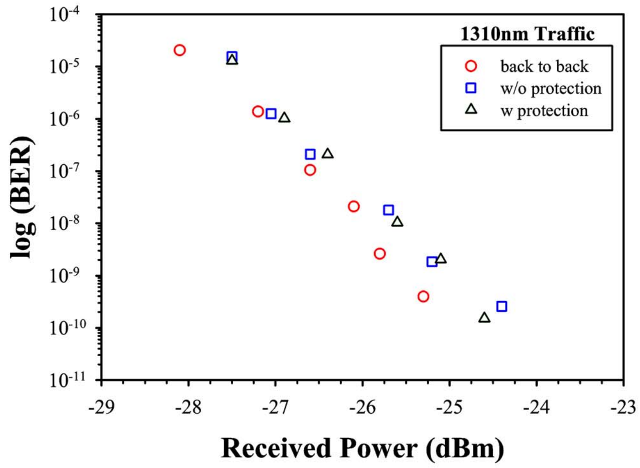
Moreover, Ref. 5 also provides a bidirectional 1:1 protection against any fiber cut between the RN and ONUs in tree-architecture PON, and the two ONUs should be a group to obtain bidirectional protection. Also, each ONU needs to add two OSs, a wavelength division multiplexing (WDM) filter, and two monitor apparatus to provide a bidirectional way against fiber fault. Compared with Ref. 5, our proposed self-healing ring-based PON not only has a simple scheme but also has a lower cost for the self-protection mechanism.

3 Experimental Results

To realize and analyze the system performance of the proposed self-protecting ring-based PON, the proposed access network is experimented. The experimental setup is the same as in Fig. 2. Four Y-type splitters are used at each remote node (RN) to simulate a ring-based PON serving four ONUs. A transmission distance between OLT [LT(0)] and ONU_4 is 20 km long. The 1490-nm downstream and 1310-nm upstream signals have 1.25-Gb/s direct modulation. In regard to the system power budget, a 1490-nm signal will traverse five optical splitters (15 dB), and about 20-km single-mode fiber (SMF, $\alpha=0.2$ dB/km); the loss budget is about 19 dB. The bit error rate (BER) performance is measured by a 1.25-Gb/s nonreturn-to-zero (NRZ) pseudo-random binary sequence (PRBS) with a pattern length of $2^{31}-1$ for the downstream traffic between the OLT and ONU_4 without and with protection. Figure 4 shows the measured downstream BER of the PON against the received power for the back-to-back type and the downstream traffic passing through in the proposed ring-based optical network with and without protection for downstream and upstream traffic. The observed optical power penalties of Figs. 4(a) and 4(b) are very small, while the BER is 10^{-9} with and without protection. The slight penalties in the access architectures are due to the chromatic dispersion of fiber. Simultaneously, to evaluate the feasibil-



(a)



(b)

Fig. 4 BER performance of downstream traffic at 1.25-Gb/s modulation from LT(0) when the proposed Y-type splitter is applied in each RN (as shown in Fig. 2). The distance between OLT [LT(0)] and ONU_4 is 20 km long.

ity of the proposed architecture, we also measure the throughput performances of the 1.25-Gb/s downstream and upstream traffic by employing a performance analyzer with a 1518-byte frame length in the same network of Fig. 2(a). Also, the ring access network has four ONUs. Therefore, the throughput performances of downstream and upstream traffic are measures at 96.6 and 99.1%, respectively.

4 Conclusion

We propose and investigate a new ring-based power-splitting passive optical network (PS-PON) with a self-healing function to avoid fiber fault. Based on the proposed Y-type passive component in each RN, the PS-PON will retrieve protection against fiber failure. Moreover, downstream traffic performance is also measured and analyzed in this ring-based access network.

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