Simply self-restored ring-based time-division-multiplexed passive optical network

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A simply self-restored ring-based time-division-multiplexed passive optical network by a clockwise and counterclockwise circulating fiber against the fiber fault in an access system is proposed and experimentally investigated. The proposed optical line terminal and optical network unit modules can be used to prevent and protect the occurrence of fiber failure in the ring-based passive optical networks (PONs). Using the proposed self-healing access network, the ring-based PON can be revived promptly under fiber failure. The protection and restoration time of the access network is measured within 7 ms. In addition, the performance of data traffic in the access network is also discussed.

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1. Introduction

Recently, the passive optical networks (PONs) are a promising solution in overcoming the last mile bottleneck in fiber access networks [1,2]. That means that fiber access networks will provide the hugest bandwidth for both downstream and upstream traffic and relieve the bottleneck arising in this area due to mismatch between the present day's capacity and growing demand. Therefore, time-division-multiplexing (TDM) PON systems such as Ethernet PON (EPON) and gigabit PON (GPON) are already standardized [3,4] and currently operating at nominal line rates of 1.25 Gbits/s for EPON and 2.5 Gbits/s for GPON [5]. Generally, the architectures of PONs have three basic topologies, which are the bus, tree, and ring structures. The point-to-multipoint connectivity between the optical line terminal (OLT) and multiple optical network units (ONUs) is obtained employing a passive branching device at the remote node (RN). Data 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 typical wavelengths are employed: 1310 nm (λ_{up}) for the upstream and 1490 nm (λ_{down}) for the downstream transmission. When a fiber link between the OLT and an ONU is broken or cut, the affected ONU will become unreachable to the OLT. Thus, to verify fiber network protection, the alternative protection paths should be implemented [6,7]. However, the ring-based TDM-PON was discussed and investigated in a few studies [6,7].

In this paper, we propose and demonstrate a self-restored architecture in the ring-based TDM-PON to protect and prevent the occurrence of fiber failure. The protection and restoration time of the access network is less then 7 ms. Moreover, the performances of the downstream and upstream traffic are also measured and discussed in the proposed ring-based TDM optical access network.

2. Proposed Architecture

A conventional ring-based TDM-PON scheme is illustrated in Fig. 1. From Fig. 1, we assume four ONUs using a single fiber path for downlink and uplink data traffic. To connect data traffic between the OLT and each ONU in a ring-based PON, a 1×2 opti-

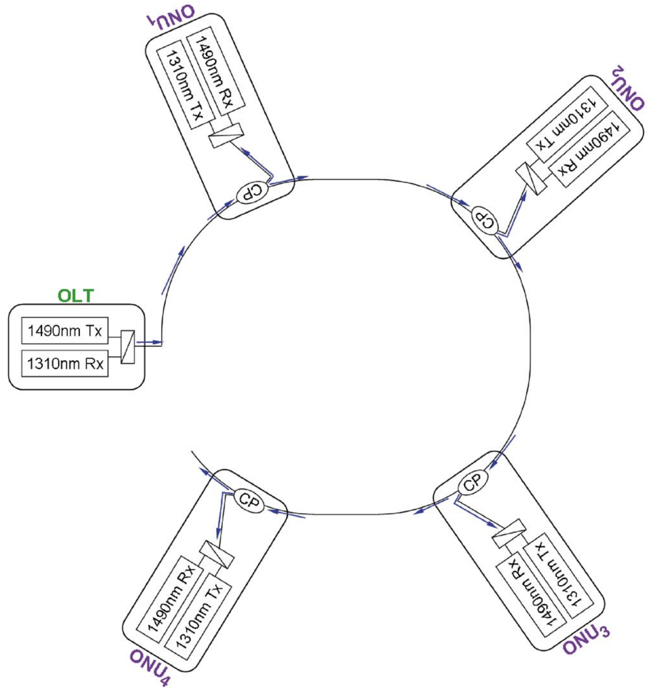

Fig. 1. Conventional ring-based time-sharing passive optical network.

cal coupler (CP) is used on each ONU, as shown in Fig. 1. The blue line with an arrow in Fig. 1 represents the transmission of downlink traffic without fiber fault. When a fiber cut occurs between ONU_2 and ONU_3, the data traffic will be unreachable behind the failure point in a conventional ring-based PON, as also shown in Fig. 1. Simultaneously, the upstream signals from ONUs after the fault point will be unable to advance. To achieve desired network survivability, two optical transceivers (TRxs) in the OLT and ONU and a dual-fiber path were reported and recommended [4,6–8]. Therefore, we propose and investigate a self-restored ring-based architecture having a single fiber path and one TRx in the OLT and each ONU for the TDM-PON access system.

Figure 2 shows the proposed self-restored ring-based architecture in TDM-PON with four ONUs. In the proposed architecture, the OLT adds a 1×2 optical CP in front of a 1490/1310 WDM CP to split the 1490 nm downstream beam passing through clockwise (CW) and counterclockwise (CCW) circulating paths simultaneously. Besides, each ONU also adds a 2×2 optical CP and a 1×2 optical switch (OS) in front of a 1490/1310 WDM coupler. Originally, the OS is switched to the 1 position to connect the uplink traffic in a CCW path. In accordance with the proposed OLT and ONU, the transmitted traffic between the OLT and each ONU (blue line with arrow) is shown in Fig. 2 for the data connections in the normal state. The upstream data link also transmits through the same transmission path (blue line in Fig. 2). Besides, another splitting downstream signal (red line with arrow) could transmit in a CCW path without any function due to the direction of the OS, as also shown in Fig. 2. Even though each ONU receives the downstream signal in a CCW path in the normal state, the OS also blocks the traffic signals from advancing. Thus, there is no collision problem of upstream data in the normal state. As a result, the switching direction of the OS on each ONU is used to determine the data traffic in the CW or CCW path.

The protection operating mechanism of the new proposed self-restored ring-based TDM-PON will be introduced as follows. Assume that four ONUs are employed in the proposed ring-based access network and the downstream signal splits into two beams for the CW and CCW paths. In the normal state, the connections between the OLT and each ONU transmit through a CW path. When a fiber fault occurs between ONU_2 and ONU_3, as shown in Fig. 3, ONU_3 and ONU_4 will not receive any information from the 1490 nm signal. Since ONU_3 and ONU_4 do not receive the downstream signal at this time, the media access control (MAC) of ONU_3 and ONU_4 will control the OS to switch to the 2 position. Then ONU_3 and ONU_4 could retrieve the downstream signal

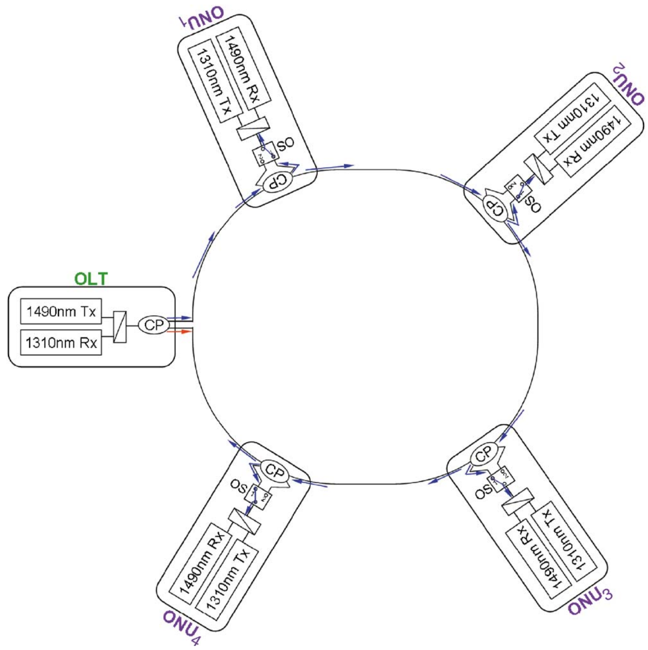

Fig. 2. Proposed self-restored ring-based architecture in TDM-PON with four ONUs in normal state.

through a CCW path, as shown in Fig. 3. That is to say, the OS will switch automatically to the 1 or 2 position depending on whether the 1490 nm photodiode of each ONU receives the downstream signal. Therefore, as mentioned before, the data traffic of ONU_1 and ONU_2 are through the CW path (blue line) and ONU_3 and ONU_4 are through the CCW path (red line), as seen in Fig. 3. When the fiber failure is restored, all the ONUs will transmit data through the CW path again. Besides, the TDM-PONs use the multipoint control protocol (MPCP) method to calculate the different round-trip times (RTTs) from the OLT to each ONU due to the different transmission paths between the OLT and each ONU. Thus, the RTTs between the OLT and each ONU can be recalculated for reconnecting data traffic when the fault is occurring in the pro-

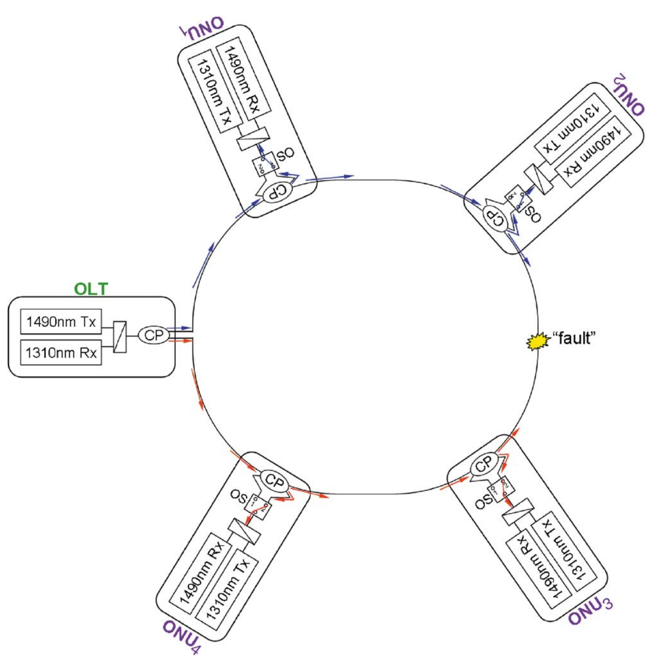

Fig. 3. Proposed self-restored ring-based architecture in TDM-PON with four ONUs when a fault occurs between ONU_2 and ONU_3.

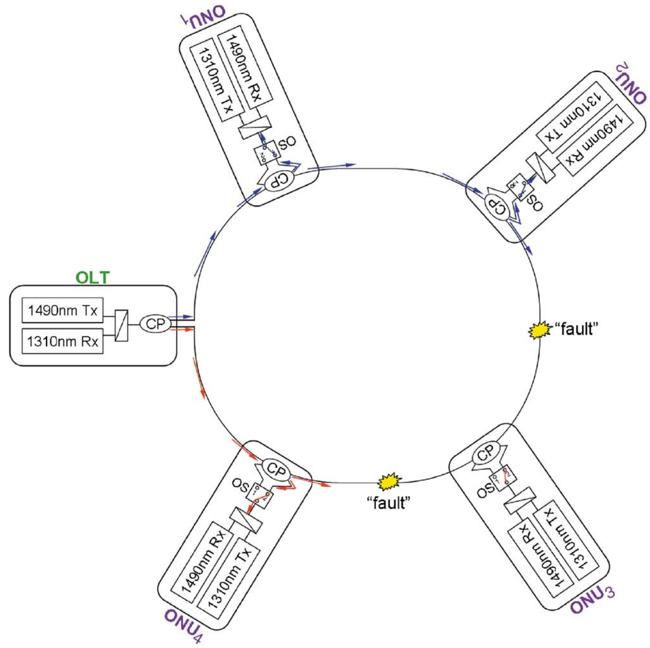

Fig. 4. Proposed self-restored ring-based architecture in TDM-PON with four ONUs when two faults occurs between ONU_2 and ONU_3 and ONU_3 and ONU_4, respectively.

posed protection PON. As a result, the proposed self-protected ring-type PON does not effect the transmission efficiency of the access network when the transmission traffic path is changed.

When two fiber faults occur simultaneously between ONU_2 and ONU_3 and ONU_3 and ONU_4, in the proposed ring-based access network (as illustrated in Fig. 4) ONU_3 would not connect any downstream signal from the OLT. However, this is not enough to produce the probability of two fiber faults at the same time in the proposed PON. The disconnection between the OLT and ONU may be a fiber cut or an ONU failure. The proposed architecture can be used to protect the system from the fiber cut, but cannot detect the ONU failure. Therefore, the problem of ONU failure needs more study for the proposed ring-architecture.

3. System Testing and Analysis

To verify the performance of the proposed self-restored ring-based TDM-PON system, an experiment is performed. The experimental setup is similar to Fig. 2 and four ONUs are employed for the simple self-protected fiber access network. A transmission distance between the OLT and ONU_4 is 20 and 5 km long, respectively, when the data traffic is in CW and CCW paths. The 1490 nm downstream and 1310 nm upstream signals have 1.25 Gbit/s direct modulation in the test ring-based PON system. The output powers of 1490 and 1310 nm lasers are 2.1 and 1.9 dBm. Moreover, in regard to the system power budget of the PON system, the traffic signal will traverse five CPRs (15 dB), an OS (1 dB), and ~20 km of single-mode fibers (SMFs) (4 dB). The total loss budget is ~20 dB at least, when the data traffic is from the OLT to ONU_4 in the CW path without protection. When the traffic is in the CCW path with protection, the total loss budget is nearly 9 dB. Besides, the system scalability of the proposed ring architecture is ~28 dB. The bit error rate (BER) performances are measured by a 1.25 Gbit/s non-return-to-zero pseudorandom binary sequence (PRBS) with a pattern length of $2^{31}-1$ for the downstream and upstream traffic between the OLT and ONU_4 without and with protection operating. Therefore, Figs. 5(a) and 5(b) show the BER performances of (a) downstream and (b) upstream traffic at 1.25 Gbit/s modulation through CW and CCW paths between the OLT and ONU_4 under the access network without and with protection, respectively. The observed optical power penalties of Figs. 5(a) and 5(b) are smaller than 0.2 and 0.4 dB while the BER is 10^{-9} without and

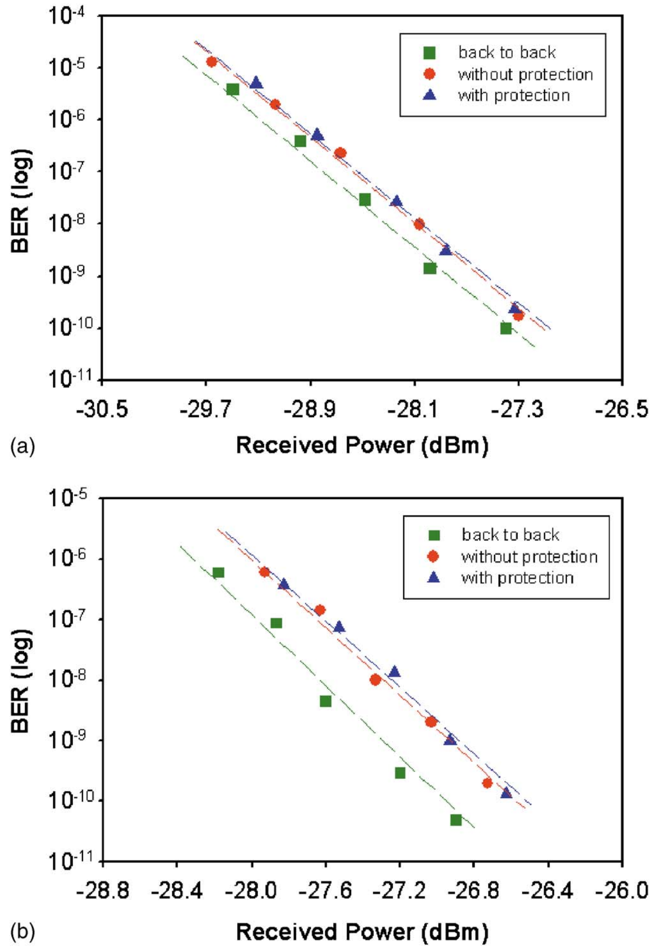

Fig. 5. BER performances of (a) downstream and (b) upstream traffic at 1.25 Gbit/s modulation through CW and CCW paths between OLT and ONU_4 under the access network without and with protection, respectively.

with protection operating, respectively. Moreover, in the proposed self-protected PON, the restorable time is measured within 7 ms due to the switching limitation of OS, as seen in Fig. 6.

At the same time, to evaluate and verify the feasibility of the proposed architecture, we also measure the throughput performances of the 1.25 Gbit/s downstream and upstream traffic by directly connecting a performance analyzer with a frame length of

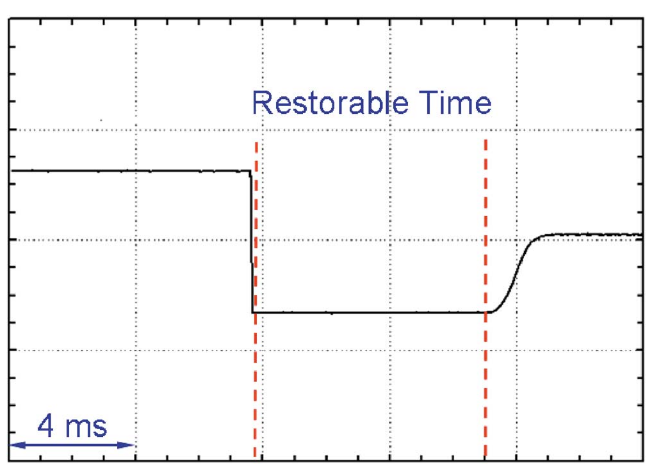

Fig. 6. The protection and restoration time of the proposed self-restored ring-based PON is within 7 ms.

1518 bytes with the same access scheme as Fig. 2 with four ONUs. Thus, the throughput performances of downstream and upstream traffic are measured at 95.2% and 98.8%, respectively, in the proposed ring-based access network. The percentage of packet loss caused depends on the transmission length and total users.

4. Conclusion

In summary, we have proposed and investigated a self-restored TDM-PON by a clockwise and counterclockwise circulating fiber against the fiber fault in TDM-PONs. In the ring-based TDM-PON, the proposed OLT and ONU modules can be used to protect the fiber fault from occurring. Employing the proposed self-healing access network, the ring-based PON can be revived promptly under fiber failure. Besides, the protection and restoration time is less then 7 ms due to the limitation of the OS in the proposed self-protected architecture. In addition, the performance of data traffic in the access network was also discussed and analyzed.

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