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Self-protecting dual-ring-architecture in time-sharing passive optical network to prevent the occurrence of fiber failure

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Abstract

We propose and experimentally investigate a self-protecting dual-ring-architecture time-division-multiplexed passive optical network (TDM-PON) using bidirectional dual-fiber path against the fiber-fault. By the proposed access network, the ring-based TDM-PON system can be revived promptly under single fiber failure. This restorable time is achieved within a few ms in the proposed ring access network. Moreover, the performance of data traffic in the optical access network has also discussed.

Keywords: Self-protecting; Ring-based; PON; TDM

1. Introduction

Recently, fiber to the home (FTTH) developments has numerous field trials and deployments performed in different types of the world [1]. This means that optical access networks will provide the hugest bandwidth for the entire fiber network traffic and reduce the bottleneck increasing in this area because of the mismatch between present data capacity and growing demand. Therefore, the passive optical network (PON) could be one of the selections in next generation fiber access networks. Latterly, the international TDM-PON standards are existence and performance, such as the Broadband PON (B-PON), Gigabit PON (G-PON) and Ethernet PON (E-PON) [2–4]. Generally, the TDM-PONs have three basic network architectures, such as bus-, tree- (or star-) and ring-type, respectively. The point-to-multipoint connectivity between the optical line termination (OLT) and multiple optical network units (ONUs) is obtained employing a $1 \times N$ optical splitter (or coupler) at the remote node (RN). Data traffic from the OLT to an ONU and the ONU to OLT mean the "downstream" link (point-to-multipoint) and "upstream" (multipoint-to-point) link. The wavelengths of 1490 and 1310 nm are used for the downstream (λ_{down}) and upstream (λ_{up}) signals in TDM-PONs. Moreover, a 1550 nm wavelength is used to provide a video service in TDM-PON. The downstream signal from OLT is broadcasting for each ONU, and the upstream signal from each ONU needs the multiple point control protocol (MPCP) mechanism to arrange the uplink. When a fiber link between the OLT and ONU is broken (or cut) due to the. environment effect, the affected ONU will become unreachable to the OLT. Thus, in order to achieve fiber network protection, the alternative protection paths should be completed [3,5–9]. In a ring-based TDM-PON, it usually uses dual-fiber path and two optical transceivers (TRx) in the OLT and each ONU against the fiber cut issues [3,6,9].

In this paper, we have proposed and demonstrated a self-protecting architecture for the ring-based PON with the dual-path and a single TRx to prevent the occurrence of fiber failure. Moreover, the performances of downstream and upstream traffic have also been measured and discussed in the ring-based fiber access network.

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2. Architecture design

A conventional ring-based TDM-PON with four ONUs using single fiber path for data traffic was shown in Fig. 1. The red arrow[1] of Fig. 1 represents the transmission direction of downstream signal (λ_{down}), and the blue arrow is upstream (λ_{up}). For example, when a fiber cut occurs between ONU_2 and ONU_3, the data traffic will be unreachable behind the failure point due to the direction limitation of optical coupler (CPR) in each ONU (as seen a inset of Fig. 1). Thus, the upstream signals from ONUs after the fault point will be unable to advance. To achieve desired network survivability, the past protection schemes using two optical transceivers in OLT and ONU were recommended [3,6,9]. Therefore, we propose and investigate a new self-protecting ring-based-architecture PON with dual-fiber path and new optical combiner in OLT and each ONU module.

When a fiber cut occurs at one point in a single ring path, this access network will be without any data traffic behind the failure point. To achieve desired network survivability, the different protection schemes are recommended for the self-protected ring-based or tree-based TDM-PONs [3,6]. However, these studies used two TRx in the OLT and each ONU, it will increase the costs in TDM-PONs. To reduce the costs and enhance the benefits, a new self-protecting ring-based-architecture PON with dual-fiber path and new optical combiner in OLT and each ONU module is proposed experimentally.

Fig. 2 shows our proposed self-protecting ring-based-architecture with double-path for the TDM-PON system. The entire data path from OLT to each ONU of Fig. 2 is transmitted through path "a" (black solid line) or "b" (dot line) for the downstream and upstream traffic. First of all, the transmission data are through fiber path "a" for downstream and upstream traffic when the PON is without fiber fault. And, fiber path "b" is prepared to prevent the occurrence of the fiber fault in path "a". That is to say, when a fault occurs in path "a", the transmission signals will switch to path "b" to retrieve the data traffic. To realize the operation mechanism for the self-protecting

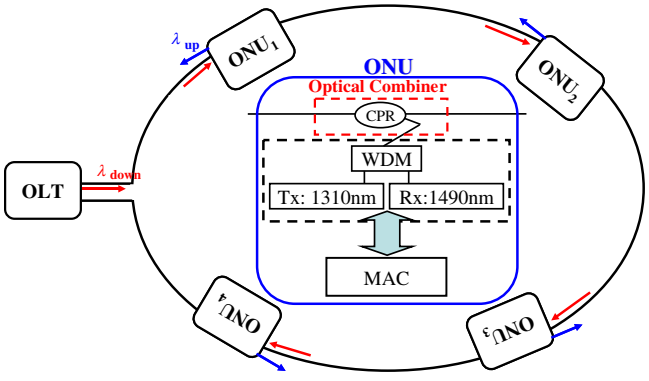

Fig. 1. Conventional ring-based TDM-PON system without self-protecting operation.

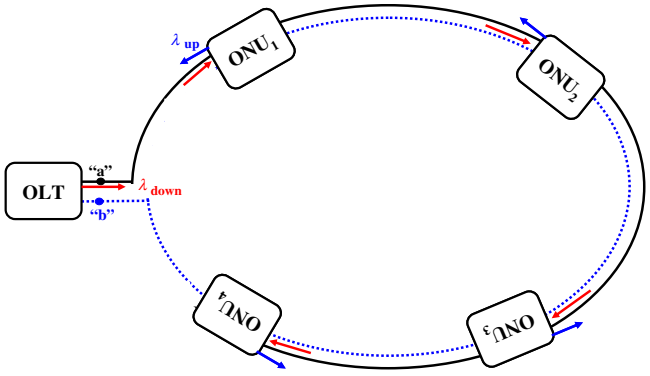

Fig. 2. The proposed self-protected ring-based PON architecture with double-path.

TDM-PON, the new proposed OLT and OUN modules will be introduced in Fig. 3. Therefore, the OLT uses a 1×2 optical switch (OS) in front of the 1490/1310 nm WDM coupler to select the signal transmissions in path "a" or "b", as shown in Fig. 3a. Each ONU employ three optical couplers (CPRs) in front of the WDM coupler to serve as an optical combiner for bidirectional data traffic, as shown in Fig. 3b. Each ONU can connect two fiber paths for the data traffics, and the switching direction of OS in OLT is used to select the one of two ring paths. In original state, the OS of the OLT locates at "1" position to transmit the data traffic through path "a" without fiber fault.

When the occurrence of fiber fault at "f" point suddenly in path "a", as shown in Fig. 4, the ONU_3 and ONU_4 does not receive any downstream signal from OLT. At this time, the OLT does not detect the upstream signal from ONU_3 and ONU_4, the media access control (MAC) of OLT will control the OS to swap to "2" position for retrieving the traffic links through the path "b". Then, the OLT can receive four upstream signals for data traffic. The entire traffic will be transmitted through fiber path "b", as seen in Fig. 4, when the self-protecting operation is open. And

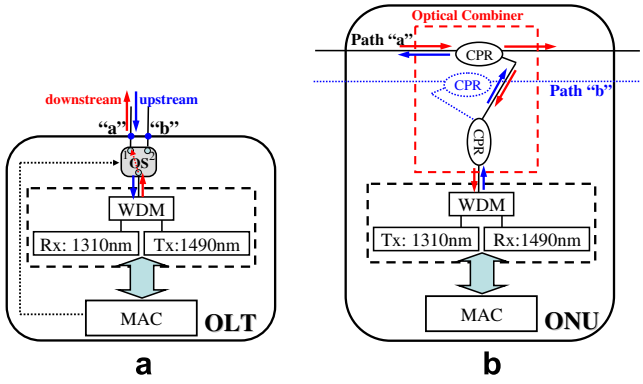

Fig. 3. Proposed (a) OLT and (b) ONU modules are used in the ring-based TDM-PONs. Red and blue lines are the transmitting direction of downstream and upstream signal, respectively, when the traffic is in path "a". (The OLT uses an OS in front of WDM coupler and each ONU add three CPRs to serve as an optical combiner.)

the transmission direction of the proposed system is shown in Figs. 4 and 5. It means that the fiber cut occurs between ONU_3 and ONU_4. Besides, if the data traffic is the same as before switching, it means that the ONU_3 and ONU_4 either are closed or get some problems. And the OS does not to switch again due to the same user number. Therefore, the OS will switch automatically to suitable position to link data traffic depending on the upstream signals. Due to the complex architectures of Refs. [7,8], the past studies need more additional components and optical amplifier to support the fiber network systems. The fiber amplifier needs to inside the system to compensate the losses due to the additional components in WDM networks. Compared with Refs. [7,8], the proposed ring-based PON system has simply architecture and easily constructs. Besides, the proposed scheme does not use more additional components for fault protection. The previously study [9] used an optical combiner in OLT and two transceivers on each ONUs with single fiber path. Using two transceivers on each ONUs and a combiner with an OS in OLT not only increase the cost but also expand the complexity of the system. Compared with Ref. [9], the proposed PON only uses an OS in OLT and one transceiver on each ONUs with bidirectional dual-fiber-path. The proposed PON is centralization in OLT and simplify the control of access network. The proposed directional combiner on each ONUs also can be regarded as placing on RN. As a result, there is not any change for each original ONU but increase the power loss in the self-protecting PON.

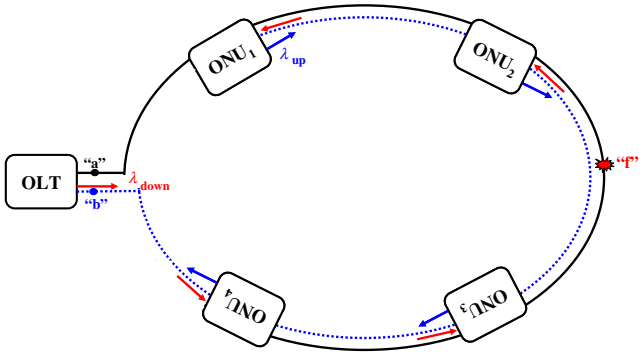

Fig. 4. The proposed self-protected ring-based PON architecture with double-path.

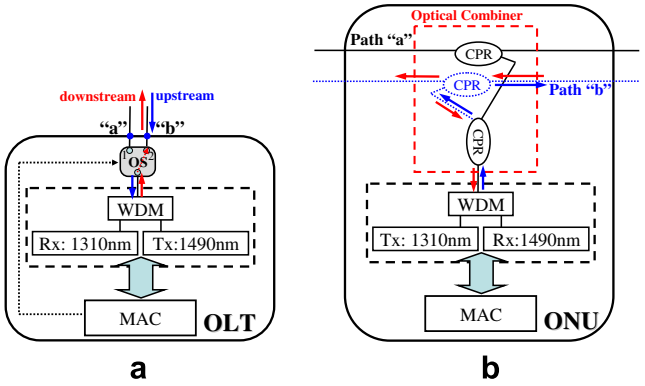

Fig. 5. Transmission direction of downstream and upstream signal, respectively, when the traffic is in path "b" and a fiber fault occurs at path "a".

3. Experiments and system testing

To verify and investigate the system performance of the proposed self-protecting ring-based PON, an experiment of the proposed access network is executed. We assume the self-protecting ring-based TDM-PON have four ONUs. A transmission distance between OLT and ONU_4 is 20 km and 5 km long in fiber path "a" and "b", respectively. The distances of OLT to ONU_1 and during each ONU are 5 km long, respectively. The 1490 nm downstream signal and 1310 nm upstream signal have 1.25 Gb/s direct modulation in the test access network. And the output powers of 1490 and 1310 nm lasers are 2 and 1.5 dBm. Moreover, the power budget of proposed TDM-PON is estimated as follows. A 1490 nm signal will traverse five CPRs (~15 dB), an OS (~1 dB) and about 20 km single mode fiber (SMF) (~4 dB), thus the total loss budget is about 20 dB. The sensitivity of optical receiver, which is used in our test system, is nearly to −32 dBm. Besides, in the proposed architecture only use four ONUs for data traffic and all the couplers employ 50:50 coupling ratio. For the proposed system, the power losses of ONU_1 to ONU_4 are 8, 12, 16, and 20 dB, respectively. It is not fair that signals between OLT and each ONUs at different positions of the ring-structure have different power losses. It maybe causes the different power loss and reduces the total number of ONU.

The bit error rate (BER) performances are measured by a 1.25 Gb/s non-return-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 when the entire traffic passes through path "a" (without protection) and "b" (with protection) under the proposed PON, respectively. Therefore, Fig. 6a and b shows the measured downstream and upstream BERs in the self-protected ring-based PON against the received power through "a" and "b" paths between OLT and ONU_4 when the proposed system is without and with protecting operation, respectively. The restorable time is measured within ~7 ms as the same as Ref. [9] due to the same component when the operating state is from abnormal to normal. The observed optical power penalties of upstream and downstream are smaller than ~0.3 dB in Fig. 6 at the BER of 10^{-9}. The proposed ring-based PON can be designed to use different coupling coupler in proper position for increasing the number of ONU. Besides, the total number of ONU used in a ring-based PON was also investigated and discussed in Refs. [6,10]. For the proposed architecture, we just show a prototype to descript the system applications in the future.

In addition, to verify and evaluate the feasibility of the proposed architecture with four ONUs, we also measure the throughput performance with 1.25 Gb/s data rate for

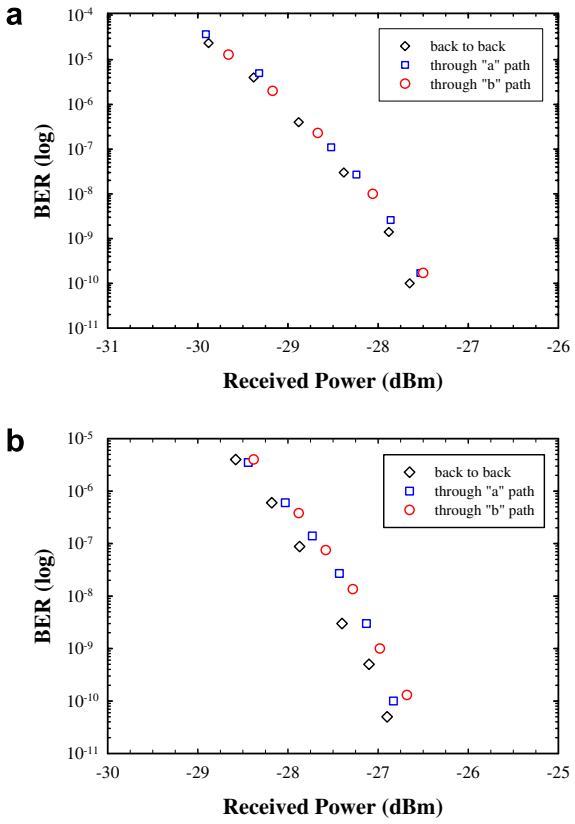

Fig. 6. BER performances of (a) downstream and (b) upstream traffics at 1.25 Gb/s modulation from OLT. The entire traffic distance between OLT and ONU_4 is 20 km long.

downstream and upstream traffic by directly connecting a performance analyzer with a frame length of 1518 byte. The throughput performance of downstream and upstream traffic is 98.6% and 99.4% in the proposed ring-based PON which are similar to Ref. [9] due to having analogous architecture, respectively, when the access system is serving four ONUs in normal operating state. When the protecting fiber path is used, the throughputs of downstream and upstream are close the above measured results.

4. Conclusion

We have proposed and investigated a new self-protecting ring-based TDM-PON with dual-fiber path to avoid and protect the fiber fault. By employing the additional optical components in OLT and each ONU, the proposed ring-based TDM-PONs will retrieve the protection against fiber failure. In the proposed protecting network system, the restorable time of the PON is approaching a few ms. Moreover, the downstream traffic performance has also been measured and discussed in this proposed ring-based access network.

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