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An autonomous recovery mechanism against optical distribution network failures in EPON

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ABSTRACT

Ethernet Passive Optical Network (EPON) is chosen for servicing diverse applications with higher bandwidth and Quality-of-Service (QoS), starting from Fiber-To-The-Home (FTTH), FTTB (business/building) and FTTO (office). Typically, a single OLT can provide services to both residential and business customers on the same Optical Line Terminal (OLT) port; thus, any failures in the system will cause a great loss for both network operators and customers. Network operators are looking for low-cost and high service availability mechanisms that focus on the failures that occur within the drop fiber section because the majority of faults are in this particular section. Therefore, in this paper, we propose an autonomous recovery mechanism that provides protection and recovery against Drop Distribution Fiber (DDF) link faults or transceiver failure at the ONU(s) in EPON systems. In the proposed mechanism, the ONU can automatically detect any signal anomalies in the physical layer or transceiver failure, switching the working line to the protection line and sending the critical event alarm to OLT via its neighbor. Each ONU has a protection line, which is connected to the nearest neighbor ONU, and therefore, when failure occurs, the ONU can still transmit and receive data via the neighbor ONU. Lastly, the Fault Dynamic Bandwidth Allocation for recovery mechanism is presented. Simulation results show that our proposed autonomous recovery mechanism is able to maintain the overall QoS performance in terms of mean packet delay, system throughput, packet loss and EF jitter.

1. Introduction

The Passive Optical Network (PON) is regarded as one of the successful technologies in access network deployment. It is reported that by 2015, fibers based on PON will cover 20–30 percent of all households and 30–50 percent in 2020 [1,2]. PON has been known as the solution for delivering triple-play services to the home or business with high-speed Internet access. It not only offers huge capacity, small attenuation loss, low operational expenditures, longevity and future-proofness but also provides the lowest energy-consuming solution for broadband access networks [3]. Recent commercially available PON solutions are based on time-division-multiple-access (TDMA), such as the GPON, and EPON standards. Currently, Japan, China and Korea are developing large-scale EPON deployments built by multiple system operators. By the end of 2011, Japan already had 21 million subscribers, followed by Korea and China. In 2012, EPON networks passed more than 60 million households, and more than 20 million broadband subscribers were served by EPON [1]. In 2009, the IEEE 802.3av standard for 10G-EPON was released with multi-data rate capability, and it was followed by the IEEE 1904.1 for SIEPON in 2013 [1]. SIEPON provides interoperability of EPON equipment for the multivendor while accommodating the rich and varied nature of the existing deployments and standards [1,4].

The EPON platform density is now not only focusing on the FTTH(ome), but it is spanning many other platforms, such as FTTB(uilding), and FTTN (in combination with various copper-based technologies to cover the last 200–500 m to a subscriber) and FTTB(usiness). Currently, a single state-of-the-art EPON OLT can support between 2000 and 30,000 customers, depending on the number of line cards, port density per card, data rate support per port and the number of subscribers per single ONU [4]. Therefore, issues relating to their protection and maintenance are crucial because any fiber fault in the system will cause the network operators to experience high revenue losses and could frustrate the customers [5–7]. This can also be deteriorated by the massive information that can be carried by the EPON systems at a time because any disruption could lead the network operators to have to pay fines if service is not restored within some period of time

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[7,8]. There are several reasons why the failures occur, ranging from mechanical faults to optical or electrical faults. A cut in a feeder or DDF, a failure of an OLT or ONU transceiver and the failure of connectors or power supplies are examples of the most common locations and reasons for failures [4,5].

Recently, two approaches have been described to recover the fiber link over EPON: centralized and distributed. The distributed approach places the simplified active modules, such as miniaturized OTDR, inside the ONU [6] in which they will evaluate and measure the uplink system performance for a particular DDF and report to the CO. This approach is adequate for identifying any link degradation; however, when fiber cut occurs at the DDF, the ONU cannot communicate with the CO/OLT. It is then necessary to send a technician to the ONU site to perform a measurement from the ONU-to-splitter using a handheld OTDR. This approach is inefficient in terms of time and cost. In contrast, the centralized approach can detect, localize and measure fiber faults; however, the network operators need to provide a protection mechanism to maintain the connection between the OLT and the affected ONU. Several studies have been proposed to solve this issue [4–14], for example, studies in [11,12] use Reference Reflector OTDR to distinguish faults among branches. However, each reflector at each branch is identical; therefore, all branches need to reflect a different reflection, which is very impractical because the ONU distance is dictated by the distance of the customer from the hub. The authors in [12,13] proposed the embedded OTDR (miniaturized OTDR) integrated in the ONUs, but these studies were primarily focused on the OTDR modeling and detecting fiber faults in branches. Furthermore, fault detection and full protection techniques have been studied in WDM mesh networks and WDM-PON [7–10,14]; however, to the best of our knowledge, few studies have addressed the link resilience and service protection in the EPON system.

Aware of this issue, in the IEEE 1904.1, the definitions of link resilience and service protection are introduced for EPON systems in which two flexible protection mechanisms are discussed, namely trunk protection and tree protection [4,15]. In trunk protection, the OLT and trunk fiber are duplicated; however, when the cost becomes a major concern, only the OLT is duplicated. The latter mechanism is tree protection in which the OLT, ONU and the entire Optical Distribution Network (ODN) are protected against failure. Consequently, trunk protection is mainly focused on protecting the OLT and the feeder fiber, whereas tree protection covers the entire area, which is good but very costly. Another issue concerning the duplication of OLT is that the working and standby OLTs must communicate across the public network; thus, synchronization for provisioning and controlling the data and time become more complicated [4]. In addition, typically, a single EPON OLT is deployed to provide services to both residential and business customers, normally on the same OLT port. Therefore, in this paper, we proposed a new autonomous recovery mechanism to protect from DDF link and ONU transceiver failures to increase data service availability and minimize the impact on the network cost caused by those failures. Our proposed mechanism is primarily focused on DDF and ONU transceiver failures because nearly all ODN failures occur in the drop fiber section. Instead of duplicating the entire ODN, such as in the tree protection mechanism, we grouped all ONUs into a "Restoration Group" (*RG*) in which each group consisted of two ONUs connected via a protection line. Hence, when failure occurs at one ONU DDF or transceiver, the affected ONU will automatically switch the working line to the protection line and send the critical alarm to the OLT via its connected ONU (neighbor ONU). Afterward, this neighbor ONU handles all of the packets originating from the affected ONU and sends them to the OLT. Once the OLT receives the alarm message from the affected ONU, the subscriber traffic flow to the affected ONU is switched to the neighbor ONU, which sends the packets with the protection line Logical Link Identifier (LLID) of the neighbor ONU. The autonomous recovery mechanism avoids the Operational Expenditures (OpEx) and large service restoration times of offline troubleshooting, thus enabling stronger QoS guarantees. There are two important terminologies that will be used throughout this paper. The first is referred to as the **affected node/ONU**, which represents that the DDF between this ONU and PSC has a link fault or that the ONU transceiver had a failure. The second is referred to as the **backup or neighbor node/ONU**, which handles all of the traffic originating from/to the affected ONU.

The rest of this paper is organized as follows. Section 2 describes the proposed preventive and post-fault management mechanisms. Section 3 describes the performance evaluation and analysis of the proposed mechanisms. We conclude our work in Section 4.

2. System architecture

This section presents the proposed system architecture for the autonomous fault recovery mechanism in EPON based on the IEEE 1904.1 SIEPON standard for link resilience and service protection functions. Table 1 shows the ONU and OLT detection conditions based on the IEEE 1904.1 standard for line fault detection [15]. In the SIEPON, the OLT and ONU functions are separated into a Line OLT (L-OLT), Client OLT (C-OLT), Service OLT (S-OLT), Line ONU (L-ONU), Client ONU (C-ONU) and Service ONU (S-ONU). The L-OLT and L-ONU have the basic management functionalities as defined in IEEE 802.3 in which they are capable of sending and receiving various types of Ethernet frames, such as data, Operation

Table 1
OLT and ONU detection conditions and alarm messages [15].

Detection parameters	Descriptions	Protection switching execution	Alarm message generated by ONU	ONU action
Loss of Signal (LoS)	The ONU fails to receive any valid optical signal within TLoS_Optical (2 ms by default)	Automatically, when both the OLT and the ONU detect the LoS	*PON_IF_SWITCH_EVENT_ONU$_i$* (switch from working line to protection line) *HOLD_OVER_START_STATE* (suspend upstream transmission until next GATE message)	After sending the *PON_IF_SWITCH_ EVENT*, the ONU will suspend upstream transmission for a specific period of time and remain in the HOLD_OVER_START state until a GATE message is received
MAC LoS	The working OLT/ONU fails to receive a REPORT/GATE MPCPDU or any other frame from the OLT within TLoS_MAC (50 ms by default)	Automatically, when both the OLT and the ONU detect the MAC LoS	*PON_IF_SWITCH_EVENT_ONU$_i$* (switch from working line to protection line) *HOLD_OVER_START_STATE* (suspend upstream transmission until next GATE message)	After sending the *PON_IF_SWITCH_ EVENT*, the ONU will suspend upstream transmission for a specific period of time and remain in the *HOLD_OVER_START* state until a GATE message is received