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Providing the full DDF link protection for bus-connected SIEPON based system architecture

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ABSTRACT

Currently a massive amount of traffic per second is delivered through EPON systems, one of the prominent access network technologies for delivering the next generation network. Therefore, it is vital to keep the EPON optical distribution network (ODN) working by providing the necessity protection mechanism in the deployed devices; otherwise, when failures occur it will cause a great loss for both network operators and business customers. In this paper, we propose a bus-connected architecture to protect and recover distribution drop fiber (DDF) link faults or transceiver failures at ONU(s) in SIEPON system. The proposed architecture provides a cost-effective architecture, which delivers the high fault-tolerance in handling multiple DDF faults, while also providing flexibility in choosing the backup ONU assignments. Simulation results show that the proposed architecture provides the reliability and maintains quality of service (QoS) performance in terms of mean packet delay, system throughput, packet loss and EF jitter when DDF link failures occur.

1. Introduction

The IP traffic is predicted to increase threefold in an amount of 60 Terabytes per second from 24 billion networked devices globally in 2019. Among it, remarkably more than 60% will be occupied by the access network traffic [1]. Therefore, it is important to invest and organize a high-capacity and reliable access network technology. The next-generation access network converges voice, data, and multimedia traffic in a ubiquitous IP network. Passive optical network (PON) has been regarded as a successful solution for the growing FTTH/B (fiber-to-the-home/building) access network by operators worldwide as it has penetrated 30–70% of households in the top 10 countries with the highest penetration rate in 2015 [2]. The global passive optical network equipment market was valued at US$24.81 bn in 2014, at a CAGR of 20.7% from 2015 to 2023 to account for US$163.5 bn in 2023 [3]. Time-division-multiplexing Ethernet PON (TDM-EPON) is one of the PON architectures used in access network [4,5]. The IEEE 1904.1 for Service Interoperability in EPON (SIEPON) was released in 2013 provides multivendor interoperability of EPON equipment while accommodating many kinds of the nature existing deployments and standards [6,7]. PON users span from the connected home users, small medium businesses, campuses, enterprises, big data centers, mobile operators, Internet of things devices, education and healthcare providers, which require strict availability requirements. Therefore, network failure(s) not only means financial loss, in critical healthcare function, a network failure can mean a loss of human life. Hence, it is paramount to provide high network reliability in the PON system.

The most comprehensive step in providing high reliability and protection capability for a PON system is by equipping a redundant feature to every working component. However, the common approach done by network operators is to deploy the PON without any protection at first and then incrementally implements protection upgrade to the working apparatus [8]. A legacy PON consists of three parts: an OLT, the optical distribution network (ODN), and multiple ONUs. Furthermore, the ODN stretched from the operator central office to the customer premises consists of a feeder fiber (FF), a passive splitter, and multiple distribution drop fibers (DDFs). To protect PON from failure in the ODN, the shared FF line needs to have the first protection priority. An apparent approach is to protect it by using a redundant feeder fiber to prevent a cable cut disturbs a PON system. Meanwhile, duplicating FF also means deploying a costly optical switch or duplicating the OLT [9]. Alternatively, in [10] a pair of OLTs can protect each other where each OLT uses two different wavelengths to serve different ONU groups in a Time/Wavelength Division Multiple Access (TWDM)-PON. The IEEE 1904.1 SIEPON brings new service protection and restoration

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mechanisms which are improvements from the preceding EPON standards. SIEPON discusses two link resilience mechanism: trunk protection and tree protection [5,7]. In the trunk protection, the OLT and trunk FF are duplicated, is mainly focused on protecting the OLT and the feeder fiber, whereas the tree protection covers OLT, ONU, and the entire ODN are duplicated to protect against failures which can provide full protection but very costly. Additionally, there are several proposed methods for protecting the shared medium while reducing the cost, first architecture proposed employing dual homing line with an additional link connects the passive splitter to the adjacent PONs [11,12], adding bridge ONUs to connect the edge ONUs from multiple PONs [13], and connecting passive splitter in a ring architecture to provide fault protection by transmitting the backup transmission in a clockwise or counter-clockwise direction [14].

Protecting the latter parts of a PON (ODN and ONUs) require more complicated protection mechanisms as nearly 80% of the failure in a PON system occurs in this section [15]. In [16], instead of using the default tree architecture, in a WDMA PON, ONUs are deployed in a ring architecture with dual wavelengths with different wavelengths provide working and protection streams. Additionally, star-ring architecture also has been proposed to prioritize high priority traffic on the default tree path and use Sub-OLT to transmit lower priority traffic to other ONUs in the ring architecture [17–19]. Moreover, in [20], the usage of a preplanned backup plan is proved to be beneficial as additional pre-assigned wavelengths are dispatched to the ONUs. Later, in failure condition the ONUs are able to react independently and use the backup wavelength for recovery. To decrease the operating expense (OpEx) to be incurred in sending off technicians in the field [21], in-service integrated fault management mechanism at the DDFs in EPON is proposed. The proposed system can automatically detect and identify any signal anomalies and DDF faults in the physical layer. Additionally, to provide the necessary protection, the DDF can be duplicated to provide each ONU a working and backup transmission lines until the passive splitter. Furthermore, in [22], an autonomous protection and recovery mechanism for protecting DDF fault(s) is proposed, all ONUs in a PON are grouped into a "*Restoration Group (RG)*" in which each group has two spare ONUs connected via a protection line. However this approach limits the protection capability, as if the RG has two consecutive DDF failures, both ONUs are completely disconnected. Instead of limiting a number of ONUs to different groups, our architecture introduces a comprehensive DDF(s) protection in which every ONU can be protected by all other ONUs through the bus-protection line. The proposed bus-connected architecture provides a cost-effective architecture to have high fault-tolerance in handling multiple DDF link faults and more flexibility in choosing backup ONUs. Table 1 summarizes the characteristics comparison for the PON fault tolerance schemes abovementioned.

The rest of this paper is organized as follows. Section II presents the proposed fault tolerant bus-connected based single PON architecture and mechanism for link resilience and service protection. Section III describes the system performance evaluation and analysis of the proposed mechanism. We conclude the study in section IV.

2. Proposed architecture

The proposed SIEPON based bus-protection line for DDF(s) protection architecture in a PON is shown in Fig. 1. In SIEPON, the OLT and ONU functions can be separated into 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 functionalities as defined in IEEE 802.3. Both of them are capable of sending and receiving various types of Ethernet frames, such as data, operation administration management (OAM), and multi-point control protocol (MPCP). A C-OLT or C-ONU associates with one or more L-OLT(s)/L-ONU(s) with higher-layer functionalities, such as statistics, alarms, power saving, protection, discovery and registration, GATE generation, REPORT processing, and QoS features. Finally, an S-OLT or S-ONU has the same functionalities as a C-OLT/C-ONU but with extra service specific functions, such as Network Address Translation (NAT) and L2/L3/L4 switching [7]. In order to provide the full link protection including the FF or/and DDF failure(s), a cost-effective bus-connected multi-PONs recovery scheme is proposed in this paper, instead of duplicating the entire ODN for the trunk/tree protections defined in IEEE 1904.1. In addition, to easily understanding the detail, the system architecture is divided into three sub-sections: (1) bus-based DDF protection system, (2) fault detection and recovery mechanism, and (3) bus-connected fault DBA (B-FDBA). There are some important terminologies will be used throughout in this paper. The **affected ONU** is the DDF between the ONU and splitter has a link failure in an EPON, and the **backup ONU** is the ONU handles all of traffic originating from/to the affected ONU.

2.1. Bus-based DDF protection systems

In the proposed ONU architecture, the S-ONU type as defined in IEEE 1904.1 can support multiple-Line-ONU mode and specific functionalities. Fig. 2 shows the S-ONU architecture, it has two L-ONUs, i.e., L_1-ONU, and L_2-ONU. First, the L_1-ONU is connected to OLT through ODN and all ONUs in PON are connected via a bus protection line (L_2-ONU) for DDF(s) protection. The L_1-ONU monitors the status of the upstream and downstream optical signals, if the L_1-ONU detects a downstream/upstream line failure (the given ONU DDF link fault), the S-ONU automatically switches the working line from L_1-ONU to L_2-ONU, and all the subscriber flows will be forwarded via the L_2-ONU through the bus protection

Table 1
Fault tolerance comparison for different single PON architectures, n is number of ONU in a PON.

Architecture	Protect OLT	Number of OLT	Protect feeder fiber	Protect DDF	Number of ONU	Degree of fault tolerance for DDF	Cost
TWDM-PON with SLA-supportive [10]	Yes	2	No	No	2n	0	High
Dual-homed PON [11,12]	No	1	Yes	No	n	0	Low
WDM-PON with Bridges ONU [13]	Yes	1	Yes	No	n	0	Low
LR-PON [14]	No	1	Yes	Yes	n	1	Moderate
WDM-PON [16]	Yes	1	Yes	Yes	n	1	Moderate
WDM-PON Mesh Network [17,18]	No	1	No	Yes	n	1	Moderate
Star-Ring TDM-PON [19]	No	1	Yes	Yes	n	1	Moderate
WDM/TDM-PON [20]	Yes	2	No	No	n	0	Moderate
TDM-EPON [21]	No	1	No	Yes	n	n-1	Moderate
SIEPON [22]	No	1	No	Yes	n	1	Moderate