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Experimental evaluation of fault recovery methods in Elastic Lambda Aggregation Network

Takehiro Sato[a]**, Yoshihiro Isaji, Yusuke Nakajima, Satoru Okamoto, and Naoaki Yamanaka**
Graduate School of Science and Technology, Keio University, 3–14–1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223–8522, Japan
a) *takehiro.sato@yamanaka.ics.keio.ac.jp*

Abstract: In Elastic Lambda Aggregation Network (EλAN), fault recovery using an Optical Line Terminal (OLT) in a different Central Office (CO) is applicable due to virtualization of OLT and active Optical Distribution Network (ODN). In addition, the Time Division Multiple Access (TDMA)-based OLT sharing method has been proposed to maintain minimum connectivity of the excessive number of Optical Network Units (ONU) from a single OLT. In this letter, we report the experiments of these two fault recovery methods implemented on the software-based EλAN prototype system. The required time from failure detection to connection recovery was evaluated in these experiments.

Keywords: optical access network, aggregation network, disaster recovery
Classification: Network

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1 Introduction

With the popularization of Fiber To The Home (FTTH) in recent years, the Internet has become an essential infrastructure for our life. In today's optical access networks, Passive Optical Network (PON) systems are widely deployed as a cost-efficient FTTH solution. In the PON system, a single Optical Line Terminal (OLT) and multiple Optical Network Units (ONU) are connected by using optical fiber cables and optical splitters. In the commercialized PON systems, several protection methods that deploy backup optical fiber cables, OLTs, and ONUs have been standardized to cope with a network failure. However, multiple failures on these components can happen simultaneously in a time of disaster, such as a major earthquake. The protection method becomes unable to operate if main and backup components fail at the same time.

Elastic Lambda Aggregation Network (EλAN) has been studied as an access/aggregation integrated network that realizes high availability [1, 2]. In EλAN, optical access paths that have flexible bandwidth are set on active Optical Distribution Network (ODN) to connect OLTs and ONUs. ODN consists of all-optical devices such as Bandwidth Variable Wavelength Cross Connects (BV-WXC), and provides various topologies such as point-to-point path, point-to-multipoint tree, and ring.

In addition, OLTs and ONUs in EλAN have programmability in order to support multiple functions for various network services. Logical OLTs (L-OLT) and ONUs (L-ONU) are configured within Programmable OLTs (P-OLT) and ONUs (P-ONU), respectively. The migration method of L-OLT between P-OLTs has been proposed to achieve more flexible utilization of P-OLTs [3, 4, 5, 6]. When a failure occurs in a P-OLT or optical devices on an access path, connectivity of P-ONUs can be restored by migrating a L-OLT to another P-OLT and reconfiguring the access path. Hereinafter, this fault recovery method is referred to as the "inter-OLT restoration". Network Management System (NMS) performs coordinated control of P-OLTs and ODN. Specifically, NMS manages resources of P-OLTs (i.e., hardware and software for realizing L-OLTs), calculates routes and bandwidth of access paths for each network service, and reconfigures optical devices on ODN.

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Generally, there is a limit on the number of ONUs that a single OLT can accommodate (e.g., 256 ONUs in EλAN) due to limitations of buffer memory, link IDs, and so on. In a case of massive failure, there is a possibility that the number of surviving OLTs is very limited and some ONUs cannot be restored even if these ONUs are available and have reachability to the OLTs. To maintain connectivity of excessive ONUs from a single OLT in EλAN, the TDMA-based OLT sharing method has been proposed [7, 8]. This method enables an OLT to maintain minimum connectivity of more ONUs in a time of massive failure.

In this letter, we report the experiments of the inter-OLT restoration and the TDMA-based OLT sharing method by using the software-based EλAN prototype system.

2 Operation of fault recovery methods

In this section, we overview the inter-OLT restoration and the TDMA-based OLT sharing method in EλAN.

2.1 Inter-OLT restoration method

As mentioned in the previous section, the inter-OLT restoration method is applicable in EλAN due to active ODN and L-OLT migration.

When a central office (CO) containing multiple P-OLTs becomes incapacitated, P-ONUs connecting with these P-OLTs become unable to receive network services. To restore the connectivity of P-ONUs, NMS calculates the new placement of L-OLTs in available P-OLTs and determines if the access paths can be configured on ODN. If the access paths can be configured successfully, NMS executes L-OLT migration so that the P-ONUs receive the network services via a P-OLT in another CO. If the access paths cannot be configured, NMS iterates the calculation of L-OLT placement and the request of access path configuration until the solution is found.

2.2 TDMA-based OLT sharing method

NMS determines to apply the TDMA-based OLT sharing method when the appropriate placement of L-OLTs to restore the connectivity of all P-ONUs cannot be found by the inter-OLT restoration method. P-ONUs are divided into several ONU groups, each of which includes equal or less than 256 P-ONUs. Timeslots to communicate with the L-OLT are allocated to each ONU group in rotation. The access path on ODN is reconfigured periodically in synchronization with the timeslots to connect the L-OLT and every ONU groups.

In the TDMA-based OLT sharing method, the communication interval of each ONU group becomes large, such as few seconds. During a timeslot allocated to one ONU group, downstream data frames to other ONU groups are discarded in the L-OLT due to its buffer capacity. To solve the problem of the buffer limit and stabilize throughput, a proxy of L-OLT [7, 8] is introduced. The proxy is generated in the layer-2 network that connects the core network and P-OLTs by exploiting Network Function Virtualization (NFV) and service function chaining. The proxy buffers downstream data frames to each ONU group and transfers them to the

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L-OLT in synchronization with switching of ONU groups so that frame loss in the L-OLT is avoided.

3 Experimental evaluation

In this section, we report the experiment results of the inter-OLT restoration and the TDMA-based OLT sharing method. Fig. 1 shows the software-based EλAN prototype system implemented for the experiments.

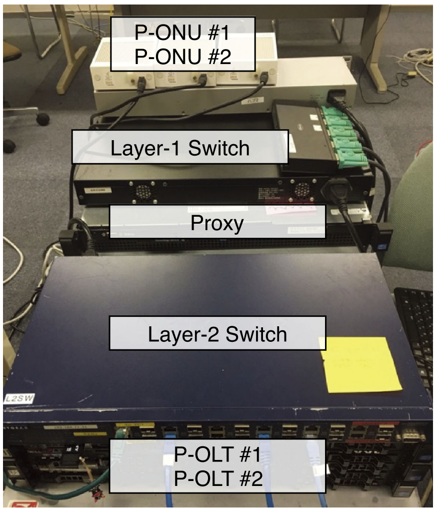

Fig. 1. Software-based EλAN prototype system.

The software-based EλAN prototype system consists of two P-OLTs, two P-ONUs, layer-2 and layer-1 switches, and the proxy utilized in the TDMA-based OLT sharing method. We assumed that the two P-OLTs were deployed in different COs. In addition, NMS and a frame generator (not presented in Fig. 1) were connected to this system.

P-OLTs and P-ONUs were implemented by using commodity Linux servers. L-OLTs that provide buffering, header modification, and forwarding of Ethernet frames were configured in each P-OLT as software on Docker containers. The layer-2 switch transfers data frames to/from appropriate P-OLTs. We assumed that P-ONU #1 and #2 belong to different ONU groups #1 and #2, respectively. Instead of ODN, an electrical layer-1 switch that transfers data signals without any processing was deployed in this experiment. This layer-1 switch can be utilized as an alternative to ODN since it is a full-mesh crosspoint switch that can connect any two ports. NMS collected the operation status information including traffic amount and alarms periodically from each L-OLT. Each of recovery methods was triggered when a L-OLT generated a Loss of Signal (LoS) alarm and NMS caught it. The frame generator sent and received two different traffic flows distinguished by VLAN IDs for ONU group #1 and #2.

3.1 Inter-OLT restoration method

At first we conducted the experiment of the inter-OLT restoration method. Fig. 2(a) shows the network configuration. When NMS received a LoS alarm from the

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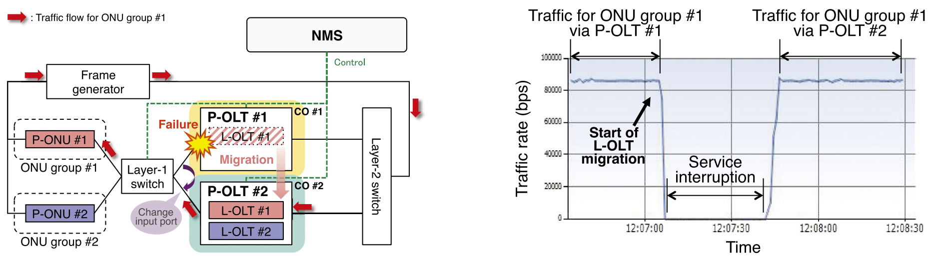
L-OLT, NMS calculated the placement of L-OLTs and determined the migration of L-OLT #1 from P-OLT #1 to P-OLT #2. Then NMS calculated the route of access path and reconfigured the layer-1 switch. After that, L-OLT #1 was migrated to P-OLT #2 so that the connectivity of P-ONU #1 was restored.

Fig. 2(b) shows the traffic rate of the flow for ONU group #1 measured at the receiving port of the frame generator. After the migration of L-OLT #1 and the reconfiguration of layer-1 switch, the traffic flow for ONU group #1 was restored through P-OLT #2 with the same traffic rate as before. The inter-OLT restoration procedure took 40.5 seconds on average from the detection of LoS to the resumption of traffic. The majority of the service interruption time was spent on the migration of the Docker container, which took 37.4 seconds on average. There is room for reducing the service interruption time to few seconds by using another L-OLT migration method, such as process migration [6].



(a) Network configuration.

(b) Traffic rate measured at frame generator.

Fig. 2. Experiment of inter-OLT restoration method in EλAN.

3.2 TDMA-based OLT sharing method

Next we conducted the experiment of the TDMA-based OLT sharing method. Fig. 3(a) shows the network configuration. In this experiment, the proxy was realized as software on a fixedly-placed Linux server. The proxy software was disabled in the normal operation, and data frames only passed through the server without any buffering and processing.

When NMS received a LoS alarm, NMS tried to calculate the placement of L-OLTs at first. However, in this experiment, there was no room in P-OLT #2 to configure a new L-OLT. Therefore, NMS decided to execute the TDMA-based OLT sharing method that L-OLT #2 accommodated both ONU groups to maintain the connectivity. NMS controlled the operation mode of L-OLT #2 periodically, in other words, allocated timeslots to ONU group #1 and #2 in rotation. NMS also turned on the proxy software, and controlled the layer-1 switch and the proxy at the same time in order to transfer the traffic flows to the appropriate ONU groups. In this experiment, the duration time of a timeslot for each ONU group was set to 10 seconds.

Fig. 3(b) shows the traffic rate measured at the receiving port of the frame generator. At first, traffic of both flows was observed at the same time. After the transition to the TDMA-based OLT sharing, each of traffic flows was appeared alternately at 10-seconds interval. The transition time from the normal operation to

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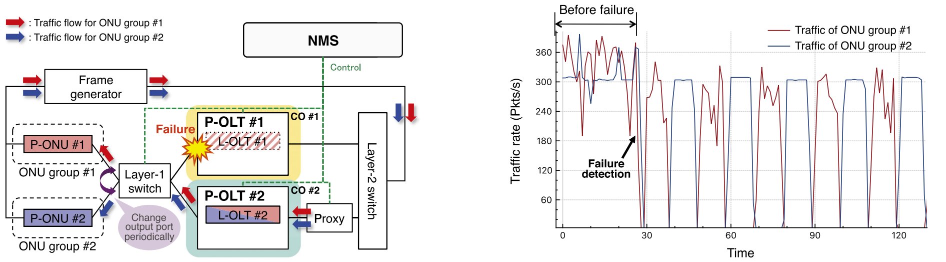
the TDMA-based OLT sharing was 1.55 seconds on average. Note that ONU group #2 had to wait additional 10 seconds to restart the communication with L-OLT #2. The switching time of ONU groups was 1.45 seconds on average.



(a) Network configuration.

(b) Traffic rate measured at frame generator.

Fig. 3. Experiment of TDMA-based OLT sharing method in EλAN.

4 Conclusion

The inter-OLT restoration and the TDMA-based OLT sharing method have been proposed as fault recovery methods in EλAN. In this letter, we reported the experimental evaluation of both methods conducted by using the software-based EλAN prototype system. In the inter-OLT restoration method, 40.5 seconds were required from failure detection to connection recovery, but this required time is expected to be reduced to few seconds. In the TDMA-based OLT sharing method, we confirmed that ONU groups can keep the connectivity by sharing a single L-OLT, with 1.45 seconds of the ONU group switching time.

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