Hitless Protection Switching Method for Passive Optical Network

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Abstract - The Passive Optical Network (PON) shares transmission facilities to provide broadband services economically. To enhance network survivability, ITU-T Rec. G.983.5 defines some protection switching methods. These methods, however, always bring about signal loss when switching is performed. Moreover, a network operator often has to replace one optical fiber cable with another that takes a different route due to constructions like social infrastructure renewal. If hitless switching is available, the operator can carry out that activity anytime without impacting users, and can also offer higher-grade broadband services. Thus the hitless protection technology for PON systems is very attractive and useful. This paper proposes hitless switching methods for PON systems based on the PON’s unique features. We also present a specific hitless protection method for GE-PON as a design example.

Index Terms - Network reliability, Network survivability, Network protection, Hitless switching, PON, GE-PON

I. INTRODUCTION

The Passive Optical network (PON) provides economic broadband services because PON shares its transmission facilities among multiple users. A PON is now providing Fiber-to-the-Home (FTTH) services and leased line services in Japan. Each PON consists of Optical Line Terminal (OLT), Optical Network Units (ONUs), and optical splitters. In the downstream direction, from OLT to ONUs, OLT transmits multiplexed packets to all ONUs, and each ONU acquires packets destined to itself, and discards all other packets. In the upstream direction, from ONU to OLT, OLT arbitrates to prevent the collision of packets from ONUs at optical splitters based on the round trip time (RTT) between OLT and ONU; OLT always ranges its ONUs before starting services.

Enhancement of PON reliability will become a more important issue in the near feature. ITU-T Rec. G983.5 was issued to improve the survivability of the Broadband PON (B-PON) [1]; its protection switching methods are based on those of Synchronous Digital Hierarchy (SDH) transmission systems, ITU-T Rec. G.783 [2]. Particularly in PON OLT needs to measure the RTT of the Side 1 link to ensure transmission control to the ONU using the Side 1 link, when the link is switched Side 0 to Side 1. Even though the POPUP procedure, a fast ranging scheme, is used, signal loss occurs and service is interrupted.

If PON protection switching could be hitless, i.e. without signal loss, network operators could offer higher-grade, no outage, services in FTTH and, more importantly, leased line services. In addition, network operators often experience situations in which fiber cables must be changed to other routes when the original route undergoes construction, for example a bridge change and social infrastructure renewal. At that time, hitless protection switching would permit them to change the fiber cable route at any time without affecting users at all. Thus the hitless protection switching function is essential for network operators.

Hitless protection switching methods for the Asynchronous Transfer Mode (ATM) technology have been studied [3], [4], [5]: One method newly defines the Operation and Maintenance (OAM) cell, and the length difference between Sides 0 and 1 is measured by using the OAM cell as a delimiter to align ATM cell sequences of Sides 0 and 1 with each other [3], [4]. Another method aligns data cells between Sides 0 and 1 by comparing data cells cell by cell without any OAM cell [3], [4]. Other methods have also been proposed [5]. These methods, designed for ATM systems, are not suitable for PON systems due to their unique features. OLT is the master and ONU is the slave in a PON; each OLT is connected to multiple ONUs, and controls and keeps surveillance over all ONUs; OLT ranges ONUs to prevent collision at optical splitters; signals from/to multiple ONUs are multiplexed on the link between splitters and OLT. Hence we need to consider these characteristics when establishing a hitless protection mechanism for PON.

This paper proposes PON hitless switching methods based on the unique features of PON. The rest of this paper is structured as follows. Section II describes the backgrounds of this study; conventional PON protection switching and a Gigabit Ethernet PON (GE-PON) system [6]. Section III proposes PON hitless protection methods; we introduce two alignment methods between Side 0 and 1 links for a fully protected PON. Section IV presents a design example for GE-PON. Section V concludes the paper.

II. PRELIMINARIES

A. Conventional PON protection switching

The PON configuration discussed here is shown in Fig. 1. It consists of an Optical Line Terminal (OLT) located in a central office, multiple Optical Network Units (ONUs) located in user premises, optical splitters between OLT and ONUs, and optical fiber connected to each other. Wavelength division multiplexing (WDM) technology is used...
on one fiber to realize upstream and downstream direction transmissions; 1490 nm wavelength downstream, and 1310 nm upstream.

B-PON protection configurations and switching methods are specified in ITU-T Rec. G.983.5 [1]. One of the configurations, a fully protected PON, is shown in Fig. 2(a). OLT and ONUs have Sides 0 and 1 for each duplicated PON line terminal (PON LT). Side 0 of PON LT in OLT is connected to Side 0 of PON LT in ONU via Side 0 optical splitters and optical fibers (this is called the Side 0 link); similarly, the Side 1 link connects the redundant equipment.

If the Side 0 link is being used and then fails, traffic is switched to the Side 1 link by OLT and ONU. Before switching, OLT needs to start ranging the ONUs on the Side 1 link to control ONU transmission based on the RTT of Side 1. During this process, services are interrupted. More specifically, this is shown in Fig. 2(b), which is taken from ITU-T G.983.5. OLT detects LOS, in the Side 0 link after some time-out period, and enters the POPUP procedure to range the ONUi on the Side 1 link. After completing the ranging process, OLT switches the Side 0 link to Side 1. As a result, as shown in Fig. 2(b), services are interrupted for the period given by the time sum of LOS, detection time, POPUP guard time, and POPUP completion time; POPUP is defined as a fast ranging method in ITU-T G.983.5.

### B. GE-PON System [6]

In preparation for Section IV, the GE-PON system is outlined here. Its actual bit rate is 1.0 Gbit/s; line bit rate is 1.25 Gbit/s due to the use of the 8B/10B coding. Its transmission unit is an Ethernet frame whose preamble field contains Logical Link Identifier (LLID) together with error protection, Cyclic Redundancy Check - 8 (CRC-8). LLID is set by the OLT to indicate ONU destination; each ONU acquires only its frames according to LLID.

To make it possible to control ONU transmission in the upstream direction, OLT first ranges each ONU and assigns a unique LLID to it. This procedure, called the discovery process, is shown in Fig. 3; Fig. 3(a) shows overall discovery sequences, and Fig. 3(b) shows OLT ranging ONU in the discovery process.

In the discovery process, OLT sends a discovery GATE message whose LLID indicates broadcast to all ONUs. In general, a GATE message contains time stamp $t_1$ which means message send time based on OLT’s clock (counter), grant start time $t_2$ and grant length $T_2$, which indicates time and duration, respectively, when the ONU is permitted to send based on ONU’s clock.

Upon receiving a discovery GATE message, the unregistered ONU first sets $t_1$ into its clock (counter) to synchronize its clock to that of OLT where the time difference corresponds to the distance between OLT and ONU; ONU then sends a REGISTER_REQ message to request registration. REGISTER_REQ messages from multiple ONUs may collide at the optical splitter, and thus the message is sent at $t_1^*$ ($t_1^* = \text{random time} + t_1$ ONU clock value). OLT receives a REGISTER_REQ message at $t_1$ based on OLT’s clock, extracts its time stamp $T_2^*$ from it, and thus obtains RTT as $T_2 = t_2 - t_2^*$.

Next, OLT assigns a LLID to the ONU via a REGISTER message, and then sends a GATE message with the assigned LLID to the ONU to confirm the assignment. The ONU replies by sending a REGISTER_ACK message. That completes the discovery process.

The OLT controls ONU’s transmission after the discovery process as shown in Fig. 4. A GATE message, which indicates the destination ONU’s LLID, contains time stamp $t_1$, send start time $t_2$, and duration $T_2$ for the ONU. The ONU updates its clock using $t_1$, and sends Ethernet frames at $t_2$ for period $T_2$ based on ONU’s clock. Since the clocks of OLT and ONU are synchronized, OLT can receive Ethernet frames from the ONU at the intended time $t_3$ by setting $t_2$ to $t_3 - \text{RTT}$ in a GATE message.
III. PROPOSED HITLESS PROTECTION SWITCHING

A. Basic concept

To realize hitless switching, the (1+1) configuration is adopted so the same packets always are transmitted over Side 0 and 1 links. The (1+1) configuration discussed below is shown in Fig. 2(a).

Hitless protection switching is made possible by making the same packets arrive simultaneously at the Side 0-1 link selector in OLT and ONU, and selecting valid packets packet by packet. Inserting a fixed alignment delay into the shorter link of Sides 0 and 1 allows the same packets to arrive at the selector simultaneously.

We now consider whether it is possible to realize hitless protection switching if the packets arriving simultaneously at the Side 0-1 link selector in OLT and ONU are not the same. An example of this case is shown in Fig. 5. Fig. 5(a) shows two packet sequences that are offset by two packets at the selector. If a buffer is not used before the selector, the selected packet sequence is shown in Fig. 5(b); the order of Packets B and C are changed after the selection and Packet D is lost due to the selection of overlapped Packet B. That is not obviously hitless. The use of a buffer yields Fig. 5(c); Packet B(0) with error is discarded, and then correct Packet C(0) is stored in a buffer. When Packet B(1) comes and is judged as correct, Packet B(1) is selected. Then correct Packet C(0) is read from the buffer. Packet D(0) is once stored in a buffer, and is read after Packet C(0). It follows that Packet C(0) is delayed by the Side 0 and 1 difference in time. Thus, the method shown in Fig. 5(c) needs not only the same buffer size as the above alignment delay inserting method, but also complex buffer control. Moreover, it causes packet delay variations that are not desirable for traffic sensitive to packet jitter. Thus, we adopt the above alignment delay inserting method.

We next consider the position to insert the alignment delay and the delay value to align the Ethernet frames on Side 0 and 1 links.

Fig. 3. Discovery process

Fig. 4. OLT’s transmission control to ONU

Fig. 5. Switching without aligning Sides 0 and 1
B. Position of Side 0 and 1 alignment delay

Inserting a fixed alignment delay into the shorter link of Sides 0 and 1 allows the same packets to arrive at the selector simultaneously. If the delay is given in OLT, the burden of ONU will be decreased, and shared effects will be obtained. We, however, find out that the delay must be inserted in each ONU as described below.

ONUs are located in different distances from OLT. Even Side 0 and 1 links of the same ONU are also different in length. Packets to all ONUs are consecutively and densely multiplexed over Sides 0 and 1 feeders. An example is shown in Fig. 6. Side 0 link of ONU_A and ONU_C is longer than Side 1 by one packet for simplicity; Side 1 link of ONU_B is longer than Side 0 by one packet as shown in Fig. 6(a). Downstream multiplexed packet sequence is shown in Fig. 6(b). If the alignment delay is given in OLT, the original packet sequence shown in Fig. 6(b) must be converted to the sequence shown in Fig. 6(c) after the alignment delay is given to each shorter link. This conversion decreases link utilization quite a lot. We need to maximize the link utilization of the feeder to operate PON effectively and efficiently.

Therefore, to provide the appropriate alignment delay to each shorter link, we must set it in each ONU. Namely the delay is set at the ONU receive side so that the same packets from ONU are aligned on Side 0 and 1 at the ONU selector. Similarly the delay is set at the ONU send side so that the same packets from ONU are aligned on Side 0 and 1 at the OLT selector.

C. Acquisition of Side 0 and 1 alignment delay

We need to obtain the alignment delay value \( \delta_i \) for ONU, Fig. 7 shows that \( \delta_i \) equals 50% of the difference \( \Delta \) between RTT0 and RTT1 for ONU.

Next we propose two methods for obtaining \( \delta_i \) based on the PON’s ranging functionality.

[Method 1] OLT ranges ONU via Side 0 and 1 links, and gets RTT0 and RTT1. OLT next informs ONU of \( \delta_i = \Delta/2 = |RTT1 - RTT0|/2 \) and the shorter link indication, Side 0 or 1 using a suitable packet. ONU receives the packet, and inserts the delay of \( \delta_i \) into the indicated link on both receive and send sides.

[Method 2] ONU measures the time difference, \( \delta_i \), in the arrival times of the same control packet sent simultaneously by the OLT for ranging over Side 0 and 1 links, and then inserts \( \delta_i \) into both receive and send sides of the link that delivered the control packet first. Note that \( \delta_i \) should update continually in both methods. Methods 1 and 2 are both effective and the selection of which to use depends on the intention of the PON system implementer. Method 1, unlike Method 2, ensures that control of upstream transmission timing is retained by the OLT. However, Method 1 requires some packet modification to transfer the delay value \( \delta_i \) and shorter link indication.

IV. DESIGN EXAMPLE OF GE-PON

A. Items for Method 1

(1) Setting alignment delay

In GE-PON, OLT ranges ONU and gives it the logical link identifier (LLID) in the discovery process as shown in Fig. 3. In the process, it obtains RTT0 and RTT1, calculates \( \delta_i \) as \( |RTT0 - RTT1|/2 \), and then informs ONU of \( \delta_i \) and the shorter link indication. We propose that GATE messages be used to carry this information.
We next consider the number of bytes required for a new field in the message. 1 bit is used to indicate the shorter link. The use of 7 bits of one byte allows $\delta_i$ values of up to 2.03 $\mu$s ($=2^{27} \times 1 \times 16$ ns), because the clock count unit is 16 ns in both OLT and ONU [4]. This represents a fiber length difference of about 400 m, and thus one byte is not sufficient. If two bytes are used, $\delta_i$ values of up to 524.3 $\mu$s ($=2^{15} \times 1 \times 16$ ns) are supported which corresponds to approximately 100 km, and so the use of two bytes is proper. ONU$_i$ first obtains the delay value $\delta_i$ and shorter link indication from the new two byte field of the GATE message just after the REGISTER message shown in Fig. 3(a) and then inserts the delay of $\delta_i$ into the indicated shorter link in both receive and send side.

(2) Updating alignment delay
After the discovery process, OLT continually updates RTT$0$ and RTT$1$ by sending the GATE message and receiving the responded REPORT message. From the latest RTT$0$ and RTT$1$, OLT obtains the alignment delay value $\delta_i = |\text{RTT}_1 - \text{RTT}_0(2)/2$ and the shorter link, and sends them to ONU$_i$ in the next GATE message. ONU$_i$ receives the message, and reflects the new $\delta_i$.

(3) Time management
For Method 1, OLT always measures RTT$0$ and RTT$1$. Hence, ONU$_i$ needs to have independent clocks, or counters in PON LT Sides 0 and 1, to allow OLT to range ONU$_i$ via Side 0 and 1 links separately.

B. Items for Method 2

(1) Setting alignment delay
The discovery GATE message is used for measuring the alignment delay value $\delta_i$. It is sent simultaneously via Side 0 and 1 links to OLT to ONU$_i$. It arrives at PON LT Sides 0 and 1 of ONU$_i$ at different times due to different link lengths as shown in the left hand side of Fig. 7. ONU$_i$ measures time difference $\delta_i$ by starting the counter at the moment the first discovery GATE message of one side arrives and by stopping it the moment the same message arrives on the other side. ONU$_i$ then inserts the delay of $\delta_i$ into both receive and send sides of the link over which the first message arrived.

(2) Updating alignment delay
We consider how to update the alignment delay value $\delta_i$ after the discovery process. ONU$_i$ receives normal GATE messages from OLT to get to transmit Ethernet frames. ONU$_i$ can use these messages to measure $\delta_i$. Thus it reflects the new $\delta_i$.

(3) Time management
As described before, ONU$_i$ sets time $t_1$ carried by the timestamp of the latest GATE message to its clock or counter. For Method 2, ONU$_i$ distance is taken to be that of the longer link, and thus its clock is set by the timestamp of the GATE message that arrived at ONU$_i$ last. ONU$_i$ needs to have one clock shared by Side 0 and 1 links, and one counter for measuring $\delta_i$.

C. Common items for Methods 1 and 2

1) Detection of invalid Ethernet frames
OLT and ONU selectors must determine the validity of frames one by one to pass packets with no errors. Invalidity is indicated by detection of clock loss, 8B/10B code violation, LLID’s CRC-8 error, Frame Check Sequence (CRC-32) error, and frame length of less than 64 bytes or longer than 1518 bytes (1522 bytes if IEEE802.1Q is used).

2) LLID management
There are two LLID approaches; one per link (i.e. two per ONU) or one per ONU. Though OLT measures RTT separately on Sides 0 and 1, we use the latter approach since it minimizes the management overhead; LLIDs are assigned as follows. During the discovery process, after OLT obtains RTT$0$ and RTT$1$, it sends the same REGISTER message that contains the assigned LLID value in the information field over Side 0 and 1 links to the ONU that sent a REGISTER_REQ message, as shown in Fig. 3(a). The ONU extracts the same LLID of Sides 0 and 1, and uses it.

V. CONCLUSION
We proposed two hitless protection switching methods for PON based on the PON’s ranging functionality. To realize simple hitless protection switching, we adopted the approach of aligning the packets of Sides 0 with those of Side 1 at the ONU and OLT selectors, and selecting valid packets one by one. We clarified that alignment delay must be set in the ONUs, not the OLT. We introduced two methods for determining the value of alignment delay; one determines the delay from the difference in RTTs over Side 0 and 1 links based on the ranging mechanism that PON inherently possesses, and the other measures the time difference when the same ranging packet arrives at an ONU from Side 0 and 1. For each method, we presented a method for updating the alignment delay. In addition, we applied the proposals to GE-PON as a design example. This method is also applicable to G-PON, but due to space constraints we will present it in another paper.

REFERENCES


