Improvement in Maintenance and Operation of 10G-EPON System

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FTTH (Fiber To The Home) is the mainstream broadband service in Japan, and the number of its subscribers has been increasing. Many of those subscribers are using telephone service, terrestrial digital television service, and video-on-demand service provided by IP networks. Therefore, FTTH systems are increasingly required to have high stability and the same redundancy that a telephone switchboard has. To meet this demand, we have developed the next-generation FTTH technology 10G-EPON (10 Gigabit Ethernet Passive Optical Network) system that provides the protection function to achieve redundancy at the time of maintenance or emergency. It also includes the in-service firmware update function. This paper presents the evaluation results of this system and introduces our approaches to the improvement in maintenance and operation of 10G-EPON system.

Keywords: FTTH, 10G-EPON, protection

1. Introduction

As of December 2012, there were 53.6 million broadband service subscribers in Japan. Among them were 23.54 million FTTH (Fiber To The Home) subscribers, and this number has been growing by 1.5% each quarter[1]. The mainstream FTTH access technology is the GE-PON (Gigabit Ethernet Passive Optical Network) system, which was standardized by the IEEE 802.3 Working Group in June 2004. It has already been eight years since the technology was first introduced in Japan. Since then, the number of video service channels has been growing, and the spread of smartphones has increased offload traffic. In addition, expectations concerning ultra-high-quality video broadcasting, which typically uses 4K or 8K resolutions, have been growing, along with anticipation of an increase in the number of terminals and the spread of cloud data communications. Under such circumstances, needs have arisen for network access technologies that are superior to the GE-PON technology in speed and capacity. To respond to such needs, in September 2009, the IEEE 802.3 Working Group standardized the 10 Gigabit Ethernet Passive Optical Network (10G-EPON) technology, which is based on the GE-PON technology but is ten times faster. Following this standardization, the IEEE P1904.1 Working Group established the standard for Service Interoperability in Ethernet Passive Optical Networks (SIEPON) in June 2013, to standardize the 10G-EPON system specifications.

Owing to the GE-PON technology, FTTH services provide not only Internet connection and telephone capability; they also provide terrestrial digital television retransmission and multi-channel video transmission, using the system's high-speed capacity. These services are used by a great number of people. FTTH services are an important part of our infrastructure today, and FTTH-providing access devices are required to operate as stably as conventional telephone switchboards. Sumitomo Electric Industries, Ltd. has been committed to researching and developing such access devices since the very beginning of the introduction of broadband services and has been supplying them to the market. Recently we developed a 10G-EPON system that complies with the SIEPON and can operate stably during software updates or at the time of an interruption, such as a failure, and have evaluated its performance on an actual system. This paper presents our evaluation results.

2. 10G-EPON System

2-1 Requirements

A newly introduced 10G-EPON system is required to operate with the existing optical fiber network that was installed for the GE-PON system as well as with the GE-PON optical network units (ONUs) built on the users' side, to minimize investment. In addition, compared with the GE-PON system, the 10G-EPON system's transmission speed is ten times as fast, and is therefore expected to lower investment cost by enabling multiple branching. Sumitomo Electric has been committed to the verification and validation of compatibility between the 10G-EPON system and GE-PON ONUs and of multiple branching, through the trial production of asymmetric 10G-EPON devices[2], and the development of 10G-EPON communication LSI processors[3].

Concerning the maintainability and operability of the 10G-EPON system, there are expectations of reduction in the operational costs incurred by recovery operations in the case of interruptions, such as line failures, or by device software updating operations for functional improvement or defect repair. The system is also expected to reduce the service downtime spent on those operations. To meet such expectations, a 10G-EPON system must be able to minimize service downtime and switch lines, and update software without human intervention.

This paper describes the results we achieved to improve 10G-EPON maintainability and operability. They are the stand-by OSU (optical subscriber unit) switching function and software updating function, both of which can switch line paths while retaining connection with 10G-EPON ONUs.

2-2 Overview of the 10G-EPON system

We recently developed a 10G-EPON optical line terminal (OLT) and optical network unit (ONU), the latter of which is built on the user's side. The OLT consists of optical subscriber units (OSUs), which are line units that supply 10G-EPON lines, a concentrator unit that concentrates those lines and transmits data to the upper-layer network (core network), and a control unit that controls individual units in the OLT and provides control interface for the administration unit (**Fig. 1**). The OSUs built in the OLT are connected to the optical switch unit and each OSU supervises its lower-layer ONUs. The OSUs in the OLT include one stand-by OSU, thus enabling N:1 redundancy switch (OSU protection). The optical switch unit can switch the ONU connection path to the stand-by OSU when instructed to do so by the control unit. **Table 1** shows the specifications of the 10G-EPON system.

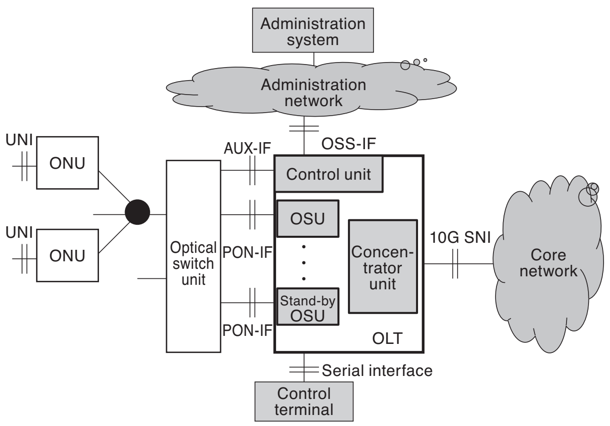

Fig. 1. Configuration of the 10G-EPON System

Table 1. Specifications of the 10G-EPON System

PON interface	10GBASE-PR30
Service Node Interface (SNI)	10GBASE-LR
User Network Interface (UNI)	1000BASE-T
Administration interface	100BASE-TX Serial interface (RS232C)
Number of PON branches	128 branches maximum
SIEPON functions	Power saving, security, eOAM, etc. (compliant with Draft 3.0 Package B)
Maintainability and operability functions	N:1 OSU protection service Un-interrupted software updating

2-3 Compliance with standards

The IEEE 802.3 standardizes the lower layers of GE-PON and 10G-EPON systems, such as the physical (PHY) layer, which determine the optical intensity and encoding, and the media access control (MAC) layer, which specifies frame transmission and receiving. Upper layers differ in specifications among service providers and device vendors. The already introduced GE-PON systems had difficulties in interoperability. The SIEPON specifies three system configurations, Package A, Package B, and Package C, based on the GE-PON systems already in use in major countries, to enable interoperability of 10G-EPON systems, including GE-PON systems. Based on the SIEPON (Draft 3.0), the 10G-EPON system we have developed has functions compliant to Package B, which is a set of system specifications for Japan.

3. Functions for the Improvement of Maintainability and Operability

3-1 N:1 OSU protection function

When used with a 10G-EPON system, the OSU protection is supposed to be used to perform switching when:

(1) the OLT unit has detected a failure.

(2) an operator has made an operation.

A failure that uses the N:1 protection is a failure that disables service at all the ONUs under the pertinent OSU, such as an optical link failure, or a 10G-EPON LSI processer failure. In case of such a failure, the linking-up between ONUs and PON is not guaranteed and immediate automatic switching is required.

When the N:1 protection is used in the case of an operator's operation, the reasons exist at the system administration side, such as periodical maintenance and OSU replacement. In this case, it is necessary to retain the PON linking-up of the ONUs under the pertinent OSU. Loss of communication frames that can lead to a service interruption is not acceptable.

The 10G-EPON system we have developed is provided with a buffer memory of a size sufficiently large enough to temporarily store the frames input during the switching. In addition, the system utilizes high-speed switching that adjusts the timing of transferring the parameters required to retain PON linking-up from the active OSU to the stand-by OSU, the timing of temporarily suspending frame transmission, and the timing of switching paths at the concentrator

Table 2. Target Performance of OSU Protection Functions

Switching specifications	N:1 protection (N ≤ 15)
Failure detection	• Automatic switching at the time of OSU failure, no OSU response, and optical fiber shutdown • Switching in 5 seconds after failure detection
Operator's operation	• Manually switching to the stand-by unit and switching back from the stand-by unit • Retention of PON linking-up • No frame loss

unit, thus preventing frame loss within the OLT. **Table 2** summarizes the performance targets of the developed OSU protection functions.

3-2 Service-uninterrupted software updating function

Although the 10G-EPON system is required to work stably, it is unavoidable for system maintenance and operability to repair detected OLT software defects and to update OLT software to incorporate new functions. It is common to reboot devices when software is updated, but PON lines can be used for telephone calls, which can be emergency calls. It can therefore be difficult to reboot the OSUs that supply such phone call services. If software updating is possible without service interruption, notifying users of such an interruption is unnecessary, and software can be updated irrespective of whether an emergency call is being made. Thus such service-uninterrupted software updating can improve system reliability and reduce operational cost.

OSU software updating without service interruption is possible if the OSU protection function is used. However, the newly developed 10G-EPON OLT system is provided with the function of updating OSU software without interrupting the service and without influencing other devices, while not using the protection function.

OSU software is configured as shown in **Fig. 2**.

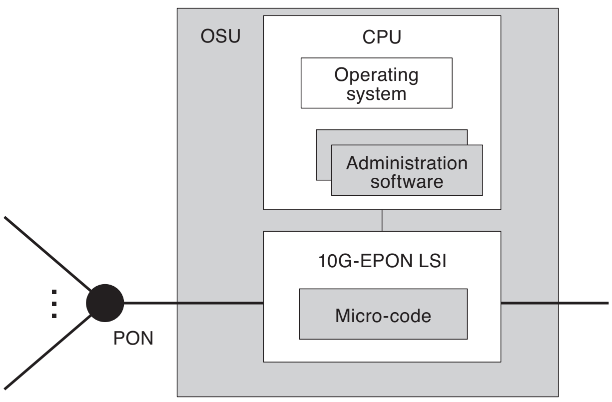

Fig. 2. OSU Software Configuration

The operating system is the boot program that operates under the administration central processing unit (CPU) of the OSU. The operating system provides basic functions such as the interruption and scheduling of the administration software programs, which operate individually. The administration software programs are the software that operates the 10G-EPON system and device drivers that control such devices as the 10G-EPON LSI processor. The microcode is downloaded to the device and operates within the device. In the function included in this new system, the administration software and microcode that are directly concerned with the operation of 10G-EPON service are the targets of improvement for service-uninterrupted software updating. This especially applies to microcode downloaded in the 10G-EPON LSI processor.

The administration software is configured from modules, each of which can be updated independently. When updating is finished, the processing status of the module before updating is retained, making it possible to perform updating without influence on major devices that are transmitting frames.

The microcode of the 10G-EPON LSI processor is directly related to the operation of MPCP[*1] and DBA[*2] in the user traffic signal conduction inside the LSI processor, so that if the processing of the microcode is stopped during microcode updating, frame transmission on the PON line stops. To prevent this, we provided multiple microcode-processing units in the OSU, enabling one unit to continue microcode execution while another unit undergoes microcode updating. Before and after the updating, the processing concerning PON frame transmission is taken over among the units. As a result, microcode updating can be done without frame loss that can cause service interruption, while PON linking-up is retained.

Table 3 lists the requirements during OSU software updating.

Table 3. Requirements for OSU Software Updating

Operating software updating	Not included in this function. Updated when OSU is rebooted.
Administration software updating	PON linking-up is retained. Updating is performed without frame transmission interruption. No frames are lost.
Microcode updating	PON linking-up is retained. Updating is performed without frame transmission interruption. No frames are lost.

To update the operating software, the OSUs require rebooting, temporarily stopping the service. However, the OSU protection function enables software updating without stopping the service. Thus, these updating functions can be used conveniently case by case. When updating is full-scale and involves the entire software, including the operating software, the OSU protection function is conveniently used. In the case of small-scale software updating, such as defect repairing and functional improvement, this service-uninterrupted function is suitably used.

4. Field Evaluation

4-1 N:1 protection function

Photo 1 shows photographs of the OLT and ONU of the 10G-EPON system we have developed.

(a) OLT appearance

(b) ONU appearance

Photo 1. Appearance of the 10G-EPON System Device

Figure 3 illustrates the evaluation test system. The OLT is provided with an active OSU and stand-by OSU, and multiple ONUs are connected to the active OSU. A network analyzer is connected to the ONU UNIs and the service node interface (SNI) of the OLT. We performed switching to the stand-by OSU while transmitting test frames, thus evaluating operational performance.

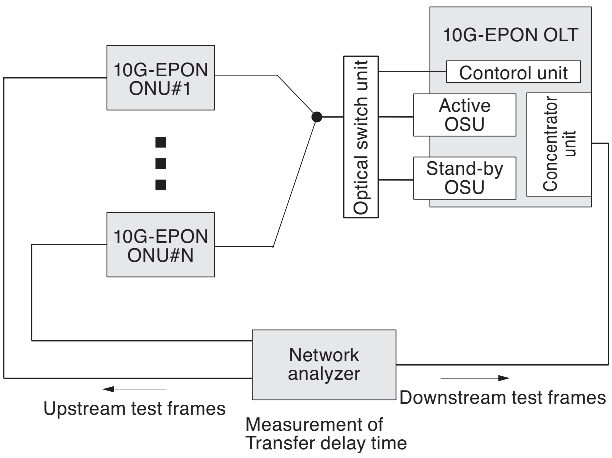

Fig. 3. Evaluation Test System

We report on the evaluation of the performance of the OSU protection function in the case of a failure and in the case of an operator's operation as follows:

(1) Evaluation of protection function at the time of failure

We evaluated the OSU protection function in the case of the following failures.

<1> OSU device failure

<2> No OSU response

<3> Optical fiber cutoff

In case <1>, we judged that a failure occurred when a major device in the OSU, such as the 10GE-PON LSI processor, was detected to have an anomaly. In case <2>, we judged that a failure occurred when control communication from the control unit was placed in a no-response status for a specific period of time. As failures <1> and <2> are difficult to produce, we used jigs to produce pseudo-failures. To evaluate operational performance in cases <1> and <2>, we measured the time between the occurrence of the pseudo-failure and when service restarted on the stand-by OSU. In case <3>, we measured the time between when the optical fiber was removed and the time when the stand-by OSU restarted the service, as the switching duration. **Table 4** shows the results.

Table 4. Switching Durations Required for Different Types of Failures (Ten ONUs Connected)

	Causes of switching	Switching duration (average)
<1>	OSU unit failure (Pseudo failure of 10G-EPON LSI processor)	4.4 s
<2>	No OSU response	34.8 s
<3>	Optical fiber cutoff	4.9 s

In case <2>, we set the time before the judgment of the failure to 30 seconds, and the actual switching duration after the detection of no response was 4.8 s. Accordingly, the newly-developed 10GE-PON system is confirmed to have the performance of switching to the stand-by OSU within five seconds after the discovery of an anomaly.

(2) Evaluation of protection function during maintenance

In the case of OSU protection activated by an operator's operation, frame transmission is temporarily suspended, and paths are switched during the suspension, to switch without frame loss. Accordingly, the suspension is represented by the increase in the frame transmission delay time. A performance evaluation of the OSU protection function was conducted through evaluation of PON linking and test frame loss, and the measurement of transmission delay time.

The developed 10G-EPON OLT is provided with operation commands that perform OSU protection. In the evaluation test, the system shown in **Fig. 4** was used, connected with five ONUs. While test frames were transmitted at each ONU at 20 Mbps upstream and downstream, we performed OSU protection with the commands and measured maximum transmission delay time.

Table 5 shows the measurement results. The OSU protection was performed successfully without frame loss. The transmission delay time was as short as less than 60 ms.

Table 5. Operator-caused OSU Protection Performance

Test frame direction	PON linking	Frame loss	Transmission delay time
Up (UNI → SNI)	No link shutdown	None	36.0 ms
Down (SNI → UNI)		None	54.8 ms

Based on the above evaluation results, we analyzed the internal processing duration during which OSU protection was in process. We calculated an estimated frame transmission delay time for each connected ONU. The results are shown in **Fig. 4**.

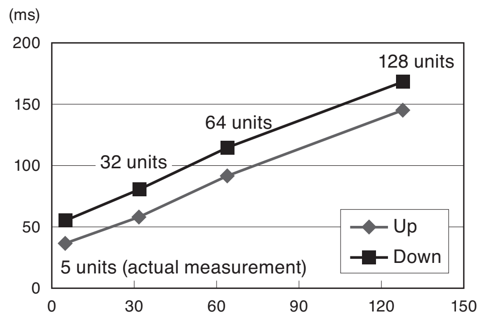

Fig. 4. Estimated Transmission Delay Time by OSU Protection for Different Numbers of ONUs

When 64 ONUs were connected, the delay time was 115 ms maximum; and 128 ONUs, 170 ms maximum. Based on these results, the present OSU protection function is judged to be able to perform switching process without frame loss. It was confirmed that the function has performance of high-speed switching even if many units are connected.

4-2 Service-uninterrupted software updating function

Concerning the updating of the microcode of the 10G-EPON LSI processor that directly influences frame transmission, we conducted an evaluation to determine if updating without frame loss is possible while PON linking-up is retained. During microcode updating, the processing of PON frame transmission is taken over between two 10G-EPON LSI processors, so that the takeover time is represented as frame transmission delay time. Accordingly, in addition to the checking of the test frame loss conditions, we measured transmission delay time, to evaluate influence on transmission frame.

Table 6 shows the conditions of PON linking and frame loss, as well as delay time measurement results obtained when the LSI processor microcode was updated by means of the service-uninterrupted software updating function, when test frames were being communicated with one ONU connected. It was confirmed that there was no frame loss due to the influence of the microcode updating on PON linking-up.

Table 6. 10G-EPON LSI Processor Microcode Updating Evaluation

Test frame direction	PON linking	Frame loss	Transmission delay time
Up (UNI → SNI)	No link shutdown	None	64.3 ms
Down (SNI → UNI)		None	72.5 ms

Table 7 shows the estimated frame transmission delay time obtained based on the actual measurements of internal switching processing time with 64 ONUs connected.

Table 7. Estimated Transmission Delay Time during Microcode Updating with 64 ONUs Connected

Test frame direction	Transmission delay time
Up (UNI → SNI)	165 ms maximum
Down (SNI → UNI)	213 ms maximum

As shown above, the service-uninterrupted software updating function can perform microcode updating without frame loss, although, when many ONUs are connected, the transmission delay time tends to be greater compared with when the OSU protection function is used.

5. Conclusion

In this present study, the N:1 OSU protection function was developed as a function to improve 10G-EPON system maintainability and operability. It was confirmed that the function has the capability of PON linking-up retention without frame loss. It was also confirmed that service-uninterrupted software updating is possible while retaining PON linking-up and without frame loss.

· Ethernet is a trademark or registered trademark of Xerox Corporation.

Technical Terms

*1 DSL (Digital Subscriber Line) : High-speed digital technology using telephone lines

*2 MPCP (Multi-Point Control Protocol) : Control protocol for GE-PON and 10GE-PON

*3 DBA (Dynamic Bandwidth Allocation) : A system or function that enables up traffic from ONUs to the OLT can be dynamically allocated.

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