Development of Communication LSI for 10G-EPON

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GE-PON (Gigabit Ethernet Passive Optical Network) systems have been widely used for broadband access services. As next generation technology of GE-PON, IEEE (Institute of Electrical and Electronics Engineers) 802.3 Working Group standardized the 10G-EPON in 2009 to provide Physical layer and Datalink layer specifications, and IEEE P1904.1 (SIEPON: Service Interoperability in Ethernet Passive Optical Networks) Working Group has been working on the standardization of upper layer protocols to improve service levels and multi-vendor interoperability for GE-PON and 10G-EPON. Along with the standardization activities, the authors have developed communication LSI for 10G-EPON, and verified its technical feasibility and conformity to the SIEPON Standard.

Keywords: FTTH, 10G-EPON, LSI, SIEPON

1. Introduction

The broadband access service network has been evolved from telephone-line based ADSL[*1] to optical-fiber based FTTH[*2], and it is now an essential infrastructure for supporting an information-intensive society. At Sumitomo Electric Industries, Ltd., we have been engaged in R&D and field deployment of broadband access equipment since the earliest stage of broadband penetration. Broadband subscribers in Japan at the end of December 2010 totaled 34.59 million, about 57% of whom (19.77 million) were FTTH[(1)] subscribers. The number of FTTH subscribers will increase even further in the future.

Most FTTH services in Japan use GE-PON (Gigabit Ethernet Passive Optical Network) systems that conform to the IEEE 802.3 Standard established in June 2004. However, given the future development of broadband services to multi-channel video delivery and cloud communications, as well as increase in number of terminals to be connected to the Internet etc., faster and larger-capacity access technology is essential for next-generation FTTH systems. In addition, there has been increasing demand for lower CO_2 emissions by reducing the power consumption of communications equipment using new information and communication technology.

In September 2009, the IEEE 802.3 Working Group finished standardizing the 10G-EPON, which can transmit data 10 times faster than the GE-PON[(2)]. The IEEE P1904.1 SIEPON (Standard for Service Interoperability in Ethernet Passive Optical Networks) Working Group has been standardizing the specifications of systems not covered by the IEEE 802.3 Standard, with the target date for completion set for June 2012[(3)]. In particular, the SIEPON Working Group has been standardizing techniques for reducing the power consumption of EPON equipment.

Under these circumstances, we have developed communication LSI for use in central office-side equipment (OLT) and subscriber-side equipment (ONU) of 10G-EPON systems, in parallel with standardization of the systems. The aim was to verify the technical feasibility of the standardization through LSI performance verification testing in a real operating environment. This paper outlines the LSI specifications and verification test results.

2. 10G-EPON

2-1 Required conditions

It is unrealistic to build a new optical fiber network by expending large amounts of money to introduce a 10G-EPON system. It is preferable to reuse an existing GE-PON optical fiber network and subscribers' GE-PON ONUs currently in use, without modification. We have been engaged in principled design and demonstration testing for 10G-EPON and GE-PON coexistence by prototyping an asymmetric 10G-EPON[(4)].

As the date of commercial 10G-EPON use approaches, demand of network providers is increasing for reduction of capital expenditure (CAPEX) and operating expenditure (OPEX). Since a 10G-EPON system increases data transmission rate from central office-side equipment to subscriber-side equipment to 10 Gbps, CAPEX and OPEX per subscriber can be saved by increasing the number of optical fiber cables branched from central office-side equipment to subscriber side equipment, thereby accommodating an increased number of subscribers. In our belief that multi-branching of optical fiber cables will be essential for the broader use of 10G-EPON services, we increased the number of branch cables that can be controlled by our new LSI from 32 to 128.

Meanwhile, network providers' concern has been growing with regard to reducing the power consumption of the information and communication equipment. For GE-PON and 10G-EPON systems, reducing ONUs' power consumption is particularly expected, because ONUs consume much more power than other units. The IEEE P1904.1 SIEPON Working Group has been working on standardizing an ONU power-saving function that suspends a portion of the ONU function when communication traffic is small. We implemented this power-saving function into the new communication LSI.

2-2 Standardization

The IEEE 802.3 Standard for 10G-EPON covers PHY layers*3 that specify light intensity and wavelength, data encoding, etc. and MAC layers*4 that specify frame formatting and transmitted/received data processing. Since the Standard does not cover the functions of higher-level layers, these functions depend on specifications established individually by telecommunication carriers and vendors. This has often posed difficulties in interoperation between equipment from different vendors.

To ensure system-level interoperability between OLT and ONUs in GE-PON and 10G-EPON systems, the IEEE P1904.1 SIEPON Working Group has been standardizing higher-level layers with the target completion date of June 2012. As of October 2011, the Working Group had drawn up Draft Standard 2.0.

Since the SIEPON Standard covers a wide range of technology areas, the SIEPON Working Group consists of five task forces (TFs) to expedite standardization. The field of technology in each TF is shown in **Table 1**. At Sumitomo Electric, we have actively been involved in the SIEPON standardization and are in charge of the editor of TF4.

GE-PON systems of different specifications are already in operation around the world, so the SIEPON Standard incorporates the different specifications. Each of the specifications is called a Package. Packages A through C have been specified. OLTs and ONUs conforming to the same Package are interoperable, even when supplied by different vendors.

Table 1. Study Themes of Each Task Force

	Name	Theme
TF1	Service configuration and provisioning	SIEPON architecture, classification, VLAN/multicast
TF2	Performance requirements and service quality	QoS metric, MPCP frame format
TF3	Service survivability	Equipment/transceiver condition monitoring, PON protection, power-saving
TF4	System/device management	ONU management, encryption, authentication
TF5	Conformance test procedures	Conformance test

3. Communication LSI for 10G-EPON

3-1 Development objective

In parallel with standardization activities, we have developed a 10G-EPON evaluation system comprising a commercial FPGA*5, so as to install and verify the standardized functions as early as possible. A 10G-EPON system consists of central office-side equipment (OLT) and subscriber-side equipment (ONUs). We have developed communication LSI for use in OLTs and ONUs. The general configuration of the 10G-EPON evaluation system is shown in **Fig. 1**.

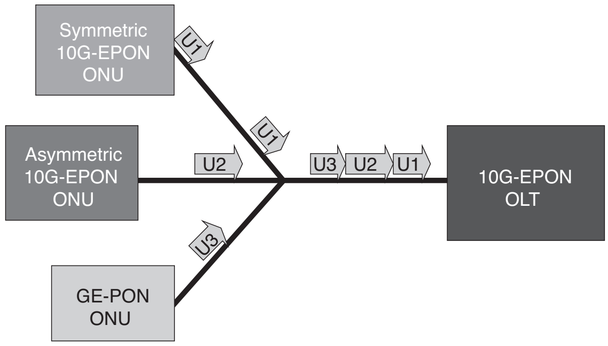

Fig. 1. 10GE-PON System

For downstream communication (from OLT to ONUs), optical signals are sent from the OLT to ONUs. Each ONU checks whether or not the signals are for the particular subscriber. In contrast, for upstream communication (from ONUs to OLT), optical signals from each ONU must be controlled so that they do not collide with each other. To eliminate collision of these upstream signals, the OLT uses a bandwidth-control technique called "dynamic bandwidth allocation (DBA)" to properly allocate signal transmission time to each ONU. The recently developed communication LSI for OLTs allows interconnection between symmetric 10G-EPON ONUs (downstream 10G/upstream 10G), asymmetric 10G-EPON ONUs (downstream 10G/upstream 1G), and GE-PON ONUs (downstream 1G/upstream 1G).

The new communication LSI has the following advantages over previously developed communication LSI for OLT:

(a) Increases number of connectable ONUs from 32 to 128.

(b) Complies with power-saving function (D2.0) currently being standardized by SIEPON Working Group.

3-2 Specifications

(1) Communication LSI for OLT

The specifications and block diagram of the LSI for OLTs are shown in **Table 2** and **Fig. 2**, respectively. As an interface with higher-level devices, the LSI contains 1G ports in addition to 10G ports, for GE-PON system com-

Table 2. Specifications of Communication LSI for OLT

PON interface	(10G) XSBI (1G) TBI
SNI interface	(10G) XAUI (1G) GMII
PON protocol	IEEE 802.3av-compliant
Number of logical links	128
Buffer size	Upstream: 256 MByte (external) Downstream: 256 MByte (external)
Logical transmission distance	90km
Power-saving protocol	SIEPON D2.0 compliant

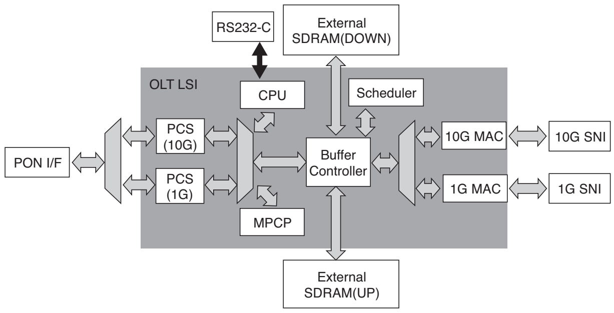

Fig. 2. Block Diagram of Communication LSI for OLT

patibility. To increase LSI storage of frames to a maximum of 128 ONUs, 256 MBytes upstream/downstream traffic, SDRAM*6 are installed outside the FPGA. The number and size of the queues to be used during operation can be set arbitrarily.

(2) Communication LSI for ONU

The specifications and block diagram of the LSI for ONUs are shown in **Table 3** and **Fig. 3**, respectively. Since the newly developed LSI using the FPGA is unavailable for directly inputting 10G serial signals from PON optical transceivers*7, the SERDES LSI is installed outside the new LSI. The SERDES LSI converts a serial signal to a parallel signal, and inputs the converted signal (XSBI) into the FPGA. The new LSI has 10G and 1G terminal interfaces, either one of which can be selected as the user-network interface for a particular operation.

Table 3. Specifications of Communication LSI for ONU

PON interface	XSBI
User-network interface	(10G) XAUI (1G) GMII
PON protocol	IEEE802.3av compliant
Number of logical links	1
Buffer size	Upstream: 4 MByte Downstream: 256 KByte

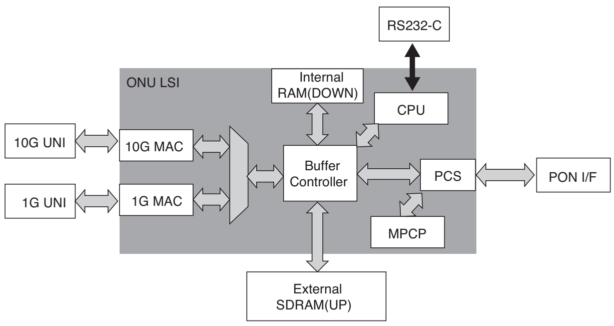

Fig. 3. Block Diagram of Communication LSI for ONU

3-3 Features

(1) Upstream DBA

In an EPON system, the upstream communication signals are transmitted on the basis of time-division multiplexing access. The OLT is informed by each ONU as to the amount of upstream frame storage, and allocates signal transmission time based on a DBA scheme to ensure fairness between the ONUs. For a 10G-EPON ONU, it is necessary to calculate the amount of frames to be stored in the buffer*8, which amount is about 10 times larger than that for a conventional GE-PON system. Although the IEEE 802.3 Standard specified that calculation time should be within 16 μs, it is difficult to sequentially check the amount of upstream frame storage within this time. To overcome this difficulty, we introduced the code vector search technique(5), which enables high-speed calculation of frame storage amount. Specifically, to calculate frame storage amount at high speed, this technique prepares an index table containing data compressed to 1/64 when stored in the buffer; the indexes are referred when frame storage amount is calculated.

(2) Multiple branching (for 128 ONUs)

The new communication LSI for OLT must communicate with 128 ONUs, which is four times more than the number of ONUs for a conventional OLT. The LSI scheduling function is therefore loaded heavily when it determines the data transmission sequence while ensuring fairness between ONUs, transmission rate, frame priority level and other factors. In upstream communication, the processing time for the above-discussed DBA is a constraint. To eliminate this constraint, we have built a circuit called an "accelerator" into the LSI. The accelerator is hardware that takes over part of the software function and processes the data at high speed. For downstream communications, we have also improved the conventional scheduling technique and have developed a circuit that can transmit the frames without reducing transmission speed, even if the number of ONUs increases to 128.

(3) Power-saving function

The SIEPON Standard specifies the control protocol between the OLT and ONUs, in order to temporarily induce their PON transmission/receiving functions to sleep when the traffic volume is small and thereby reduce power consumption. Two ONU sleep modes have been specified: Tx sleep mode, for temporarily suspending transmitter function only, and TRx sleep mode, for temporarily suspending both transmitter and receiver functions.

Figure 4 shows an example of a power-saving control protocol flow between OLT and ONU. The OLT sends a power-saving initiation command (SLEEP ALLOW) to the ONU. The ONU sends back a message (SLEEP ACK) when it accepts the command and begins sleeping intermittently (repetition of active and sleep cycles). Though **Fig. 4** shows an example in which an OLT gives a power-saving command to an ONU, it is also possible, as an option, to send from ONU to OLT a message asking for activation of power-saving control. The power-saving control is terminated when the ONU sends a sleep termination signal (WakeUP) to the OLT, or when the OLT requires the ONU to terminate the sleep mode.

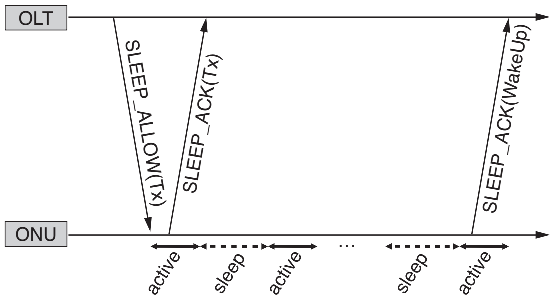

Fig. 4. Power-saving Control Protocol Flow

The communication LSI for OLT monitors downstream communication traffic volume, while the communication LSI for ONU monitors upstream communication traffic volume, to check the time appropriate for beginning or terminating the power-saving mode and thereby activate the power-saving control protocol on a timely basis.

4. Verification Testing in Actual System

4-1 Multiple branching

To verify that the newly developed communication LSI operates reliably even when 128 ONUs are connected, and that the dynamic bandwidth allocation function works as expected in upstream traffic from each ONU when the LSI is used in an actual network system, we constructed a performance verification testing system comprising, as shown in **Fig. 5**, 12 10G-EPON ONUs, 4 asymmetric 10G-EPON ONUs, and 112 GE-PON ONUs.

Table 4 shows the DBA cycle time that can be accommodated by the communication LSI for OLT. As this table shows, the time necessary for DBA processing increased as the number of supported ONUs increased. When the number of ONUs used in the test system was 32, the minimum time necessary for DBA processing was 300 μs. In contrast, when the number of ONUs was increased to 128, the DBA processing time increased to 1,200 μs. The maximum DBA cycle time could be set at 2,000 μs for both 32 and 128 ONUs, and the distance between OLT and ONUs could be extended to 20 km or more. The maximum upstream frame delay time is about three times the DBA cycle time. The remaining objective therefore is to enhance DBA efficiency and reduce DBA cycle time.

Table 4. Range of Operable DBA Cycle Time

Supported number of ONUs	Minimum DBA cycle time	Maximum DBA cycle time
32	300μs	2,000μs
128	1,200μs	2,000μs

Table 5 shows the throughput from various types of ONUs (128 ONUs in network) when the upstream traffic for each ONU was fully loaded. We confirmed that bandwidth was fairly allocated regardless of the type of ONU, even when symmetric 10G-EPON ONUs, asymmetric 10G-EPON ONUs and GE-PON ONUs coexisted in a single network system.

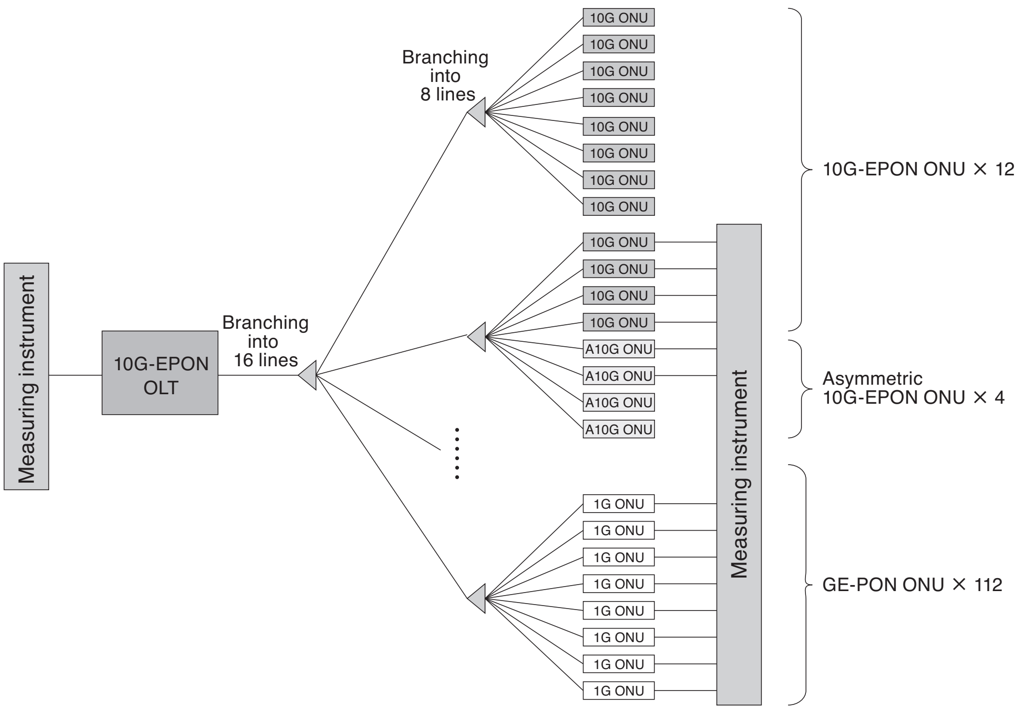

Fig. 5. Actual Equipment Verification Environment for 128 ONU System

Table 5. Throughput Measurement Results for 128 ONU System

ONU	Throughput	
	%	Mbps
Symmetric 10G-EPON	0.58%	5.7
Asymmetric 10G-EPON	0.58%	5.7
GE-PON	5.80%	5.7

4-2 Power-saving function

We implemented a power-saving function in a 10G-EPON OLT and an ONU equipped with communication LSI we originally developed, and confirmed that this function worked stably for a long time. In this confirmation test, we monitored the control frame between the OLT and ONU to check that frame format and control frame value were set as expected, and that the control sequence worked as specified. Following confirmation, we activated the power-saving function between the OLT and a GE-PON ONU equipped with commercial LSI and measured the power consumption in order to assess the validity and effect of our power-saving protocol. The dependence of power consumption on the input traffic to the ONU in each sleep mode is shown in Table 6. Each value figure in this Table is shown as a ratio to the power consumption of the ONU with no sleep and no input traffic, which was assumed to be 1. The total power consumption of the GE-PON ONU in the Tx and TRx sleep modes was reduced by about 24% and about 38%, respectively, verifying that the power-saving function was effective in reducing ONU power consumption. Since the power consumption reduction rate depends on transmitting/receiving circuit performance in each ONU, speeding stop/recovery time will further improve the power consumption reduction effect.

Table 6. Power Consumption Ratio between ONUs in Sleep Modes

Sleep mode	No traffic input	Low traffic input (upstream: 1 pps)	High traffic input (full for upstream and downstream)
No sleep	1.0	1.0	1.29
Tx sleep	0.76	0.76	1.29
TRx sleep	0.62	0.62	1.29

Measurement condition: Ratio of active time to sleep time is 1 to 10.

5. Conclusions

We have developed communication LSI for OLTs and ONUs of 10G-EPON systems conforming to both the IEEE 802.3 Standard and IEEE P1904.1 SIEPON draft standard, and have confirmed that the functions specified by the above standards can be implemented in an actual network and that the network operates stably. For multi-branching optical fiber cables and power-saving function, both of which will become essential for future commercial introduction of 10G-EPON systems, we created an actual verification environment consisting of many ONUs. Tests in the above environment verified the technical feasibility of both the multi-branching optical fiber cables and power-saving function.

* Ethernet is a trademark of XEROX Corporation.

Technical Term

*1 ADSL (Asymmetric Digital Subscriber Line): A high-speed digital communication technology that uses ordinary telephone lines. Data transmission speed of each access line is usually 1-50 Mbps. Practical transmission speed depends on distance from subscriber to central office and quality of access line.

*2 FTTH (Fiber To The Home): An ultrahigh-speed digital communication technology that uses optical fiber cables. Data transmission speed of each access line is usually 100 Mbps-10 Gbps. Practical transmission speed is independent of distance from subscriber to central office.

*3 PHY layer (physical layer): The lowest layer of an OSI reference model that specifies the hierarchical structure of a communication function. Physical specifications, encoding of transmission paths and other items are defined in this layer.

*4 MAC layer (Media Access Control layer): A sublayer of the second (Datalink) layer of an OSI reference model. Frame format, frame transmission/reception process and other items are defined in this layer.

*5 FPGA (Field Programmable Gate Array): An LSI whose circuit can be changed by programming.

*6 SDRAM (Synchronous DRAM): Low-price, large-capacity general-purpose memory used as the main memory of a personal computer.

*7 PON optical transceiver: A circuit block built into central office-side equipment (OLT) and subscriber-side equipment (ONU). This circuit converts electrical signals to optical signals and transmits the converted signals to the optic fiber cable of the PON, or converts optical signals from the optical fiber cable of PON to electrical signals.

*8 Buffer: Memory used in information communications equipment to temporarily store received Ethernet frames.

References

(1) Ministry of Internal Affairs and Communications, Japan
(2) IEEE P802.3av, "10Gs/s Ethernet Passive Optical Network"
(3) IEEE P1904.1. http://www.ieee1904.org/1/
(4) F. Daido et al., Development of Asymmetric 10G-EPON System, SEI Technical Review, No. 69, pp78-82 (Oct. 2009)
(5) Japanese Patent: no. 4003645

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