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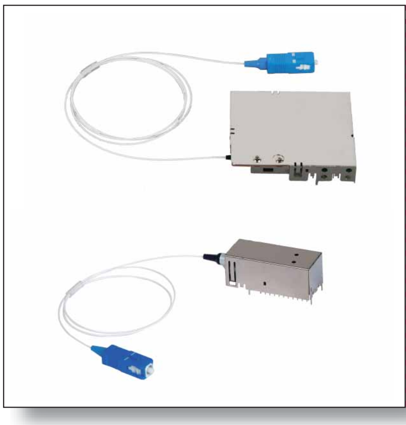
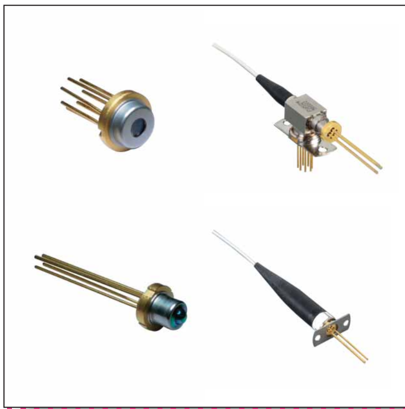
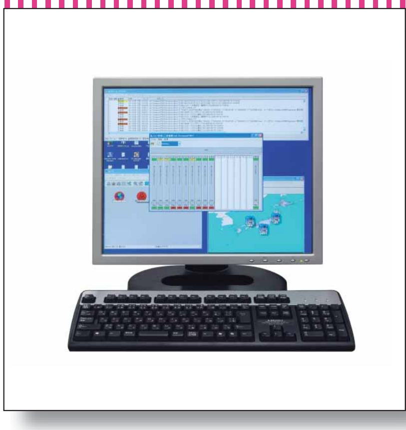
ADVANCE

Optical Access Technology







MITSUBISHI ELECTRIC

Changes for the Better

Jun. 2006 / Vol. 114

MITSUBISHI ELECTRIC ADVANCE

Optical Access Technology

Cover Story

Mitsubishi Electric Corporation has been developing optical-access equipment as the foundation for broadband communications, along with the technologies that make such equipment possible.

The photographs on the cover show some of our main products that combine to constitute a GE-PON (Gigabit Ethernet Passive Optical Network). In particular, we currently have in large-scale production the OLT (Optical Line Terminal) seen at center, the ONU (Optical Network Unit) at lower right and the Operations Support System on screen at lower left. We are now independently developing a range of optical components (upper right) and complete optical modules (upper left).

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Overview

Author: *Motoyuki Nakamura**

In Japan, FTTH (Fiber to the Home) services have been commercialized by major Japanese domestic common carriers. By August 2005, the number of FTTH subscribers had topped 3 million, showing that optical access systems have been gaining ground as a key infrastructure.

Contributing factors include the e-Japan Strategy, a national policy designed to promote broadband services, and the advancement of PON (Passive Optical Network) technology on the technical front, which pursues cost-effectiveness by using point-to-multipoint connections. Specifically, as the major domestic carriers and PON-related R&D projects have progressed with standardization, equipment vendors and parts suppliers have developed high-performance low-cost equipment and devices. As a result, optical access systems with speeds up to 1Gbps have entered commercial service.

Common carriers have already completed installing optical fiber cables as far as the network feeder points. The focus is now on constructing the last-mile optical-fiber lines from each feeder point to individual households, which is a gigantic once-in-a-lifetime project, the first since the fixed home telephone system was built. It is therefore essential to investigate the impact of NGNs (Next Generation Networks) and FMC (Fixed Mobile Convergence), which respectively represent the much-touted ubiquitous network and the use of mobile cellular telephony for final access to it, in order to determine whether optical access and FTTH-based services should indeed become part of the infrastructure of society.

This feature edition introduces technologies developed by Mitsubishi Electric Corporation in the optical access field. Going forward, we anticipate that advances in optical access technologies will stimulate the optical access market.

**Communication Networks Center*

Prospects for Optical Access Network

Authors: *Kiyoshi Shimokasa*, Hiroshi Ichibangase*** and *Kuniaki Motoshima***

Broadband Internet has spread rapidly, and FTTH (Fiber To The Home) using an optical communication system started in 2002. As of September 2005, the number of subscribers to the service in Japan totaled about 4 million, and had increased to almost 5 million by the end of 2005. FTTH has now become the second largest broadband service next to ADSL (Asynchronous Digital Subscriber Line), far ahead of CATV.

Figure 1 shows the system configuration of Mitsubishi's optical access network. The access network has reached its peak growth with the system changed from the CT/RT (Central Terminal/Remote Terminal) configuration in which multiple metal circuits are integrated optically for the subscribers that are mostly at remote locations, to the PON (Passive Optical Network) configuration in which optical splitters are installed in the access lines so that multiple subscribers are accommodated in a single optical fiber.

This paper discusses how it explodes and its main technologies.

1. Transition of Optical Access System Architecture

In the 1980s, the fiber-optic communication system replaced coaxial-cable transmission system. When it goes to the access system, optical subscriber line multiplex transmission provides an economical means to carry metal circuit subscribers when the subscribers are mostly at remote locations by integrating and connecting the subscribers via the optic-fiber system. For the CATV distribution system, the HFC (Hybrid Fiber Coaxial) system, which improves the performance by means of analog transmission of light, was developed. However, this employs an optical system for part of the access section, and it was not until the 1990s that a completely optical system was established with PON (Passive Optical Network) which branches and distributes downstream optical signals and uses TDMA (Time Division Multiple Access) for upstream signals. Initially, the bit rate was lower than 100 Mbps, but this was later increased to 150 Mbps/600 Mbps along with the hierarchy of SDH. The original multiplexing was based on ATM (Asynchronous Transfer Mode), and was later changed to Ethernet packets. The standard specifications of PON were established as G.983 series recommendations by ITU-T in 1998 [(1)]. Almost simultaneously, the 100-Mbps independent PON system was developed and put into commercial use, albeit in limited regions, as a cost-effective system. Table 1 compares the architectures of the optical access system.

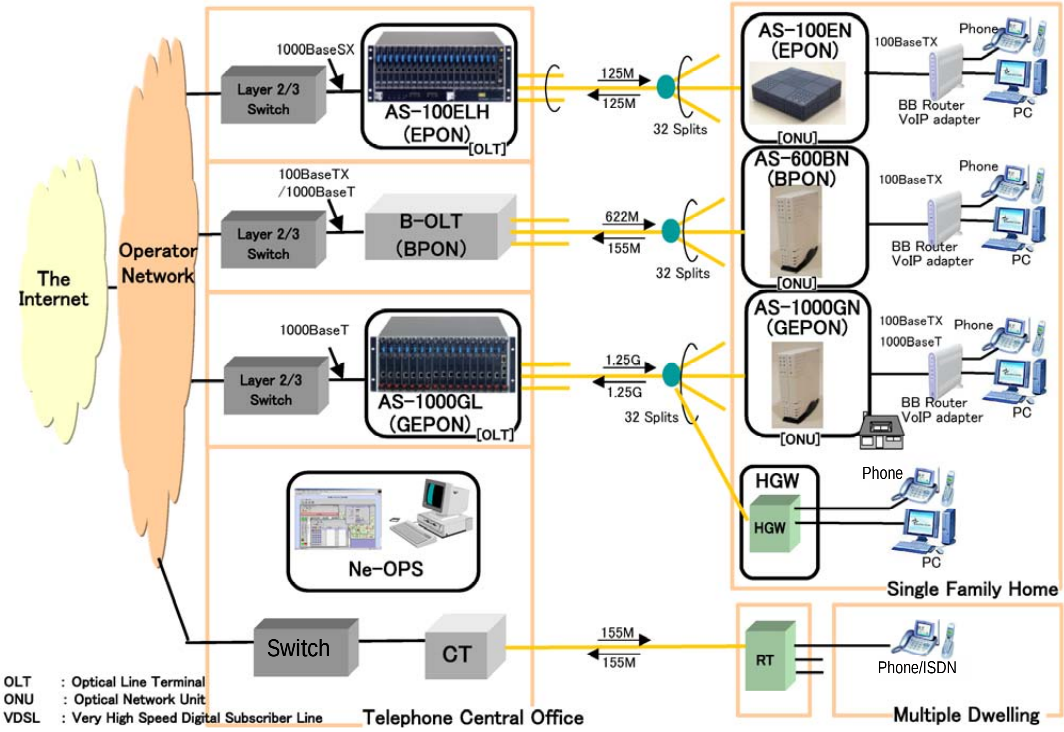

Fig. 1 Optical access network

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In the past year or two, the PON rate has exceeded 1 Gbps and the IEEE 802.3 committee established 802.3ah (EPON Standard) [2]. Several operators in Japan introduced the systems in compliance with the standard as GE-PON (Gigabit Ethernet-PON) in practical configurations. ITU-T then established the G.984 series GPON standard for PON with 1.2 Gbps for upstream and 2.4 Gbps for downstream [3]. LSIs complying with these standards have been released by chip vendors and further development of optical transmission devices in accordance with the standardized specifications have greatly boosted the applications to FTTH. Figure 2 shows the trends of services in the market and the road map for the optical access system. The element technologies supporting the optical access system are discussed in the following chapter.

2. Technologies Supporting the Optical Access System

This chapter discusses the trends in technologies supporting the optical transmission systems.

2.1 Optical transmitter and receiver technologies

The technological challenges in the optical transmitter and receiver used in the PON system are to develop burst optical transmission technologies for upstream and to improve the optical output power as well as optical sensitivity of the OLT at the central office that compensates for the transmission loss caused by inserting the optical splitter in the transmission line and the ONUs installed at the respective subscribers' premises.

To address the first technological challenge regarding burst optical transmission, a burst optical receiver circuit by means of continuous AGC and a burst optical sender circuit based on the feed-forward type APC method are used [4]. Synchronization of burst signals from the ONUs at different distances was established by developing a single-chip LSI equipped with a DLL (Delayed Lock Loop) comprising an 8-phase clock.

To address the latter technological challenge, namely a wider dynamic range, a pre-amplifier IC and a limiting amplifier IC with SiGe BiCMOS process was employed for the OLT; the pre-amplifier gain control system for burst uses the continuous AGC method. In addition, for controlling the optical output level of the ONU, the feed-forward type APC method was applied.

Regarding the development of optical devices, a module that combines a DFB laser having high output and wide range of operation temperature with a highly-efficient aspherical lens was developed. A high-sensitivity APD and low-noise pre-amplifier IC were incorporated in the receiver module to improve the optical sensitivity.

Table 1 Optical access system architecture

Optical Access System	Standardization	Transmission Rate	TDMA Method	Service
Individual PON	Non-standard	Downstream: 125Mbps Upstream: 125Mbps	Polling	Internet Access
B-PON	ITU-T G.983 series	Downstream: 150M/600Mbps Upstream: 150Mbps	Grant Control	Internet Access VOIP
GE-PON (Gigabit Ethernet-PON)	IEEE 802.3ah	Downstream: 1.25Gbps Upstream: 1.25Gbps	Grant Control	Internet Access VOIP, IP Video
G-PON (Gigabit- PON)	ITU-T G.984 series	Downstream: 2.488Gbps Upstream:	Timeslots Assignment	Triple Play
SS (Single Star)	IEEE 802.3ah TTC TS-1000	Downstream: 125M/1.25Gbps	-	Internet Access

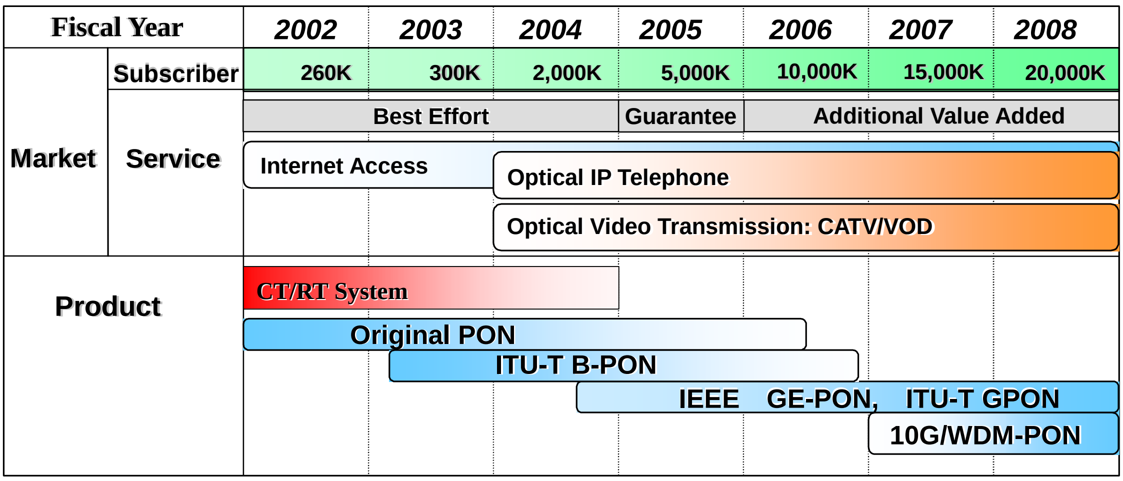


Fig. 2 Trend of service and optical access system

2.2 PON control technologies

To improve the transmission efficiency of the upstream TDMA control, the delay control method is used in which the delay time with respect to each ONU is measured in advance and transmission is executed according to the transmission timing of the furthest ONU. For downstream control, the address control of signals is done by setting the address each time and depending on the information toward each ONU. In the case of BPON, the system was arranged with the VPI (Virtual Path Identifier) of ATM (Asynchronous Transfer Mode). On the other hand, in GE-PON, MPCP (Multipoint to Point Connection Protocol) was defined to allocate LLIDs (Logical Link Identifiers) to the Ethernet packets to process the packets in accordance with the LLID (2). Regarding GPON, the OLT designates the time slot for the upstream TDMA (3).

Mitsubishi Electric, using its own PON technologies, developed the OLT/ONUs for BPON systems and increased the bit rate of GE-PON systems by an order of magnitude. While upstream transmission control called DBA (Dynamic Bandwidth Assignment) is required for such transmission features as delay and throughput in the upstream TDMA control, Mitsubishi Electric has successfully improved the transmission efficiency by proposing and developing its unique DBA technologies.

2.3 Encryption and authentication technologies

Encryption and authentication technologies are essential for protecting private information, particularly for remote communications via networks.

Since PON networks employ point-to-multipoint connections, encryption and authentication functions are also required for Layer 1. For B-PON, a simple encryption method based on the Churn method was used. A strict, powerful US government encryption standard such as AES was introduced into the IEEE standards. (2)

As for authentication, communication procedures have been established on the basis of the registration of ONUs to the OpS in B-PON. However, in GE-PON, the discovery procedure was added and connecting any ONU with the circuit immediately and automatically establishes the PON link, thus incorporating the authentication function for connections with registered ONUs.

2.4 VLAN function and priority control function

For accommodating multiple services in the optical access system, the VLAN function and priority control function are required, though it depends on the multiplexing architecture. GE-PON, in particular, uses Ethernet frames entirely for transmission, resulting in a simple unit configuration. However, the packet multiplexing function based on QoS control for multiple service control and VLAN function have been incorporated in the GE-PON system.

2.5 Operation system for optical access

In the conventional operation system for optical access, a general-purpose network control manager for integrated monitoring or a CIT (Craft Interface Terminal) for individual monitoring was generally used for operation monitoring.

However, as the capacity of the optical access system has increased, it became necessary to increase the size and performance of the operation monitoring function also. Mitsubishi Electric has met such needs by incorporating its original special control application into general-purpose network control manager.

3. Technologies in Future

ITU-T has completed the standardization of the PON for downstream 2.5 Gbps and upstream 1.25 Gbps. Although 1 Gbps PON system may seem sufficient for accommodating FTTH services, much faster PON systems may be required in regions where there are many business users who need large-capacity leased lines.

In view of this trend, the WDM-PON system that multiplexes high-speed services by means of WDM and 10-Gbps PON systems have been intensively studied. Mitsubishi Electric has obtained satisfactory characteristics with a prototype 10-Gbps PON optical interface unit and developed an SOA-EA-SOA integration device that is expected to be a key element in the WDM-PON system. These new items will be discussed in other papers.

4. Conclusion

In this paper, Mitsubishi's original technologies among all the technologies currently available for optical access systems were introduced.

Looking at the future of optical access systems, it is estimated that 30 million subscribers will be using FTTH services in 2010. Technological breakthroughs for lower cost, higher function, and higher performance must be introduced to meet such growth. Mitsubishi Electric is committed to delivering the immense technological improvements required.

References

(1) ITU-T Recommendation G. 983.1,2,3,4,5,6,7
(2) IEEE 802.3ah Standard
(3) ITU-T G.983.3/G.983.4 Recommendation
(4) Nakagawa, et al. "Newly Developed OLT Optical Transceiver for GE-PON Systems Compliant with IEEEE 802.3h"

Status toward Standardization of Optical Access Systems

Authors: *Ken Murakami** and *Tetsuya Yokotani**

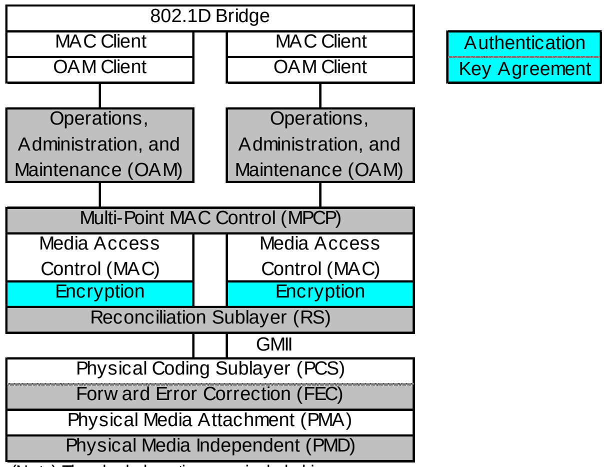
Increasing attention is directed to the PON (Passive Optical Network) system that has many merits such as reduced number of fibers and reduced area required for installation in the central office in connection with optical access systems to support broadband services. ITU-T (International Telecommunication Union – Telecommunication standardization sector) SG15/FSAN (Full Service Access Network) and IEEE (Institute of Electrical and Electronics Engineers) 802.3ah/EFM (Ethernet in the First Mile) have worked on standardizing the PON system. This paper discusses the status of standardization of security functions at IEEE and complementary technologies for the actual system.

1. Scope of GE-PON Standardization

IEEE Standard 802.3ah was established in September 2004 for the application of Ethernet technologies to access networks. The standard includes the protocol specifications for layer 2 and below with respect to the GE-PON (Gigabit Ethernet PON) that accommodates gigabit-scale two-way transmissions in the PON area. The GE-PON employs virtual links that are called logical links as the communication unit for access control, as well as bridge operation in conjunction with the logical links.

On the other hand, standardization of the security functions for the layer 2 networks including the GE-PON is being conducted by IEEE802.1AE and IEEE802.1af. IEEE802.1AE defines the encryption protocol to provide the secure communication functions to the network where MAC (Media Access Control) service is applied. In October 2005, sponsor balloting for Draft4.0 of the standard was conducted, and the draft was approved. Today, Draft5.1 has been released, which includes management specifications for such elements as MIB (Management Information Base). On the other hand, IEEE802.1af is expected to define the control of communication connections by means of authentication and the key exchange protocol for encryption. Draft0.4 contained the requirements related with the connection control based on EAP (Extensible Authentication Protocol), though it does not yet contain key exchange protocol requirements, which are being studied by the Task Group.

Figure 1 shows the protocol stack of the GE-PON and the scope of IEEE standards. The security functions under study at present include encryption, authentication, and key agreement.



(Note) The shaded sections are included in the applicable scope of IEEE standards.

Fig. 1 GE-PON protocol stack and scope of standard

2. Outline of Encryption Method Requirements and Method of Application to Actual System

Secure communication is provided by encryption of MAC frames by the sender side and decryption of the MAC frames by the receiver side on point-to-point or point-to-multipoint communication connections (secure channels). The entity that performs such encryption and decryption processes is called MAC Security Entity (SecY). The GCM-AES (Galois/Counter Mode of Operation with Advanced Encryption Standard) with 128-bit key length is employed as the default encryption method. The encryption range is from the Type/Length field to the FCS (Frame Check Sequence) of the MAC frame. As a result of encryption, SecTAG (Security TAG) and ICV (Integrity Check Value) are added as the overhead. Figure 2 shows the sequence of encryption and decryption.

Figure 3 shows the application of the encryption functions defined in IEEE802.1AE to the GE-PON system. Each logical link is equivalent to a secure channel and independent encryption/decryption processes are executed for each logical link. In a unicast logical link for point-to-point connection, different multiple encryption keys (SAK: Secure Authentication Keys)

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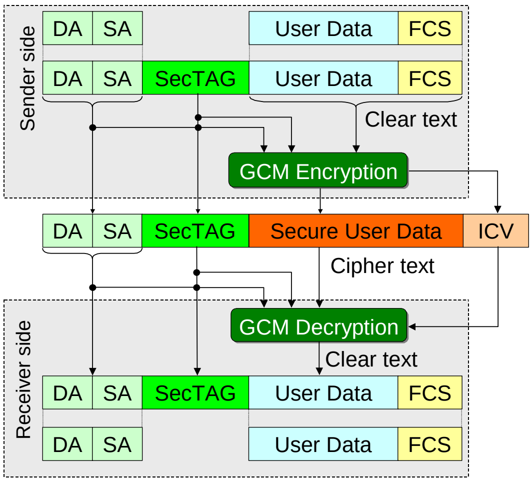

Fig. 2 Encryption and decryption sequence

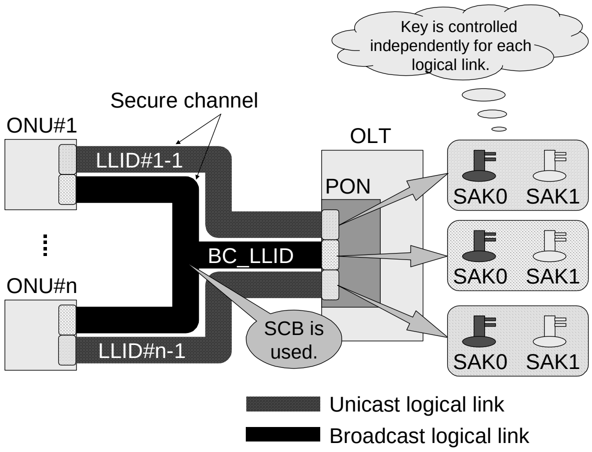

Fig. 3 Application of IEEE802.1AE to GE-PON system

are shared by OLT (Optical Line Terminal) and ONU (Optical Network Unit). On the other hand, in a broadcast logical link that executes frame distribution to all ONUs by SCB (Single Copy Broadcast), all the ONUs use the common encryption keys.

3. IEEE802.1AE/af Cooperation (Key Agreement)

SecY executes SAK-based encryption and decryption processes. SAK is periodically updated by the KSP (Key Selection Protocol) defined in IEEE802.1af. The entity that executes the KSP is called KaY (Key Agreement Entity). As shown in Figure 4, the new encryption key exchanged between KaYs by the KSP is notified to SecY via LMI (Layer Management Interface) in the equipment.

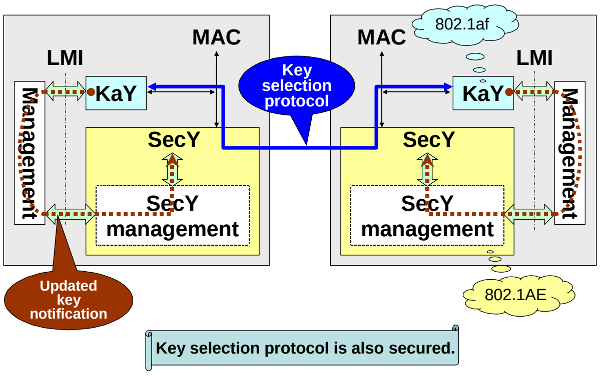

Fig. 4 Cooperation of IEEE802.1AE/af in key agreement

4. Outline of 802.3ah Provisions and Complementary Functions for Actual Operation

(1) MPCP

MPCP defines the framework of connection control of logical links and access control on logical links. In the access control on logical links, the GATE and REPORT messages of MPCP are used.

As shown in Figure 5, the REPORT message has one or more queue sets, each of which consists of a maximum of 8 queue length fields. In other words, the REPORT message is designed for cases in which a priority queue is provided for each of the 8 CoS's (Class of Service) defined in IEEE802.1p. In the actual operation of the system, queue length fields of the respective priority queues allocated to each logical link as well as the content of queue length information included in the respective queue sets should be defined, which further should be recognized in the DBA (Dynamic Bandwidth Allocation) process of the OLT.

On the other hand, the GATE message contains a maximum of 4 units of GRANT information. The relationship between these GRANTs and the priority queues allocated to the logical links is not defined. In actual operation, it is necessary to define how to allocate given GRANTs to the priority queues (Readout control according to priority queue = Priority control).

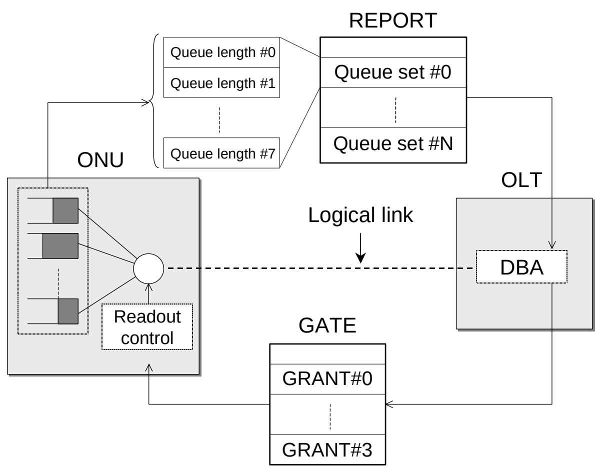

Fig. 5 Access control mechanism by MPCP

(2) OAM

OAM defines the framework of Remote Failure Indication, Remote Loopback, and Link Monitoring.

In actual operation, such functions as setting the configuration of the ONU (number of queues, size of queue, and number of logical links) and downloading of ONU firmware will be necessary.
For such upper-layer control, an Organization Specific OAM frame is defined. Since the data field of the Organization Specific OAM frame can be defined in a system-specific manner, it will be necessary to define the formats of data field and the sequence for each necessary function.

Technologies for Gigabit EPON Systems

Authors: *Michiya Takemoto** and *Hideaki Yamanaka**

With broadband services now widely available, broadband access using optical fiber has become full-fledged. The GE-PON (Gigabit Ethernet Passive Optical Network) system is the most reliable solution to FTTH (Fiber to the home). This paper describes the main technologies for the triple play services, which is provided by major network operators using the GE-PON system in Japan.

1. Outline of GE-PON System

In the GE-PON system (Fig. 1), a maximum of 32 subscribers share 1 Gbps bandwidth as the network is branched in a system configuration that consists OLT (Optical Line Terminal) in the central office, ONUs (Optical Network Unit) in the respective subscribers, fiber optics and optical splitters. The MPCP (Multi-Point Control Protocol) function is employed to control one or more ONUs connected to the OLT. Thus, Discovery Control, which detects ONUs connected to the PON interface and allocates LLID (Logical Link Identifier), and GATE/REPORT Control for sending and receiving operations in the respective ONUs, are provided. With the MCPC function, a special DBA (Dynamic Bandwidth Allocation) function that decreases delay and improves bandwidth efficiency is provided for maintaining fairness among the users and for implementing priority control in such services as VoIP and data communication systems (Fig. 2). Since downstream signals are transmitted toward all of the ONUs simultaneously in a GE-PON system, it is suitable for multicast forwarding. However, to prevent signals directed to a certain ONU from being decoded by any other ONU, a certain security function must be provided. For this particular purpose of securing secrecy between the OLT and each ONU, the AES

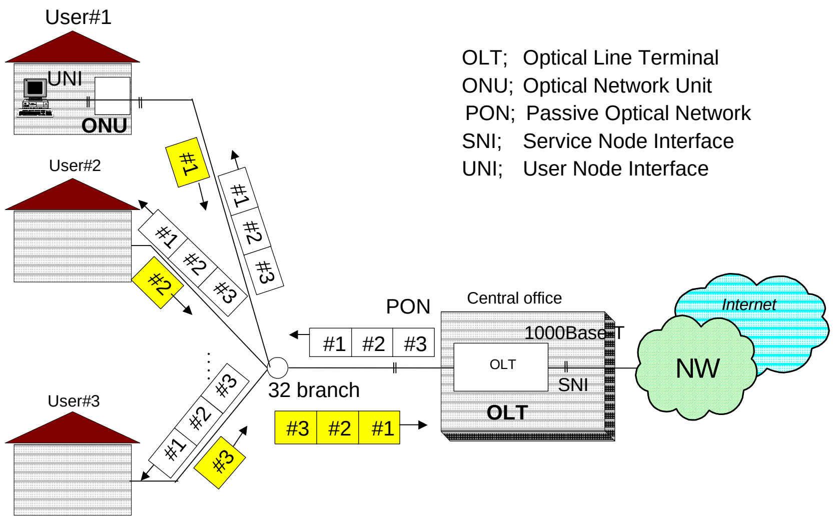

Fig. 1 GE-PON system architecture

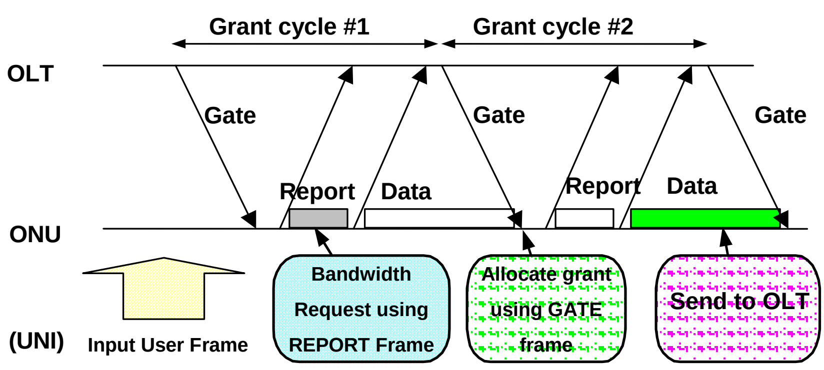

Fig. 2 Sequence of upstream bandwidth allocation

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(Advanced Encryption Standard) encryption algorithm is employed.

2. Method to Accommodate Both Voice and Data

To provide the triple-play service, both low latency for voice traffic and wide bandwidth for data traffic must be consistent.

Access control of each logical link provided with LLID is executed between the OLT and ONU to support bi-directional transmission. For the provision of multiple traffics, or multiple services, to the subscribers, priority control within a single LLID allows bandwidth control for each type of service. With this method, an increased volume of the service does not result in an increase in overhead, thus highly efficient use of the bandwidth becomes possible.

Figure 3 shows the control method in which the ONU consisting of multiple priority queues submits respective queue conditions in the form of REPORT messages to the OLT. The OLT calculates the bandwidth in accordance with the reported value and allocates the bandwidth in order from the high priority queue to the low priority queue, the latter of which is allocated bandwidth only when extra bandwidth (rest) is available. Since the ONU that has been allocated bandwidth outputs in order starting with the high priority queue, priority control for each type of service all through the PON is possible. With this single LLID accommodation method, both the priority control of high-priority services and the efficient utilization of bandwidth, which is the unique merit of the single LLID method, are available, thus making low latency and wide bandwidth compatible.

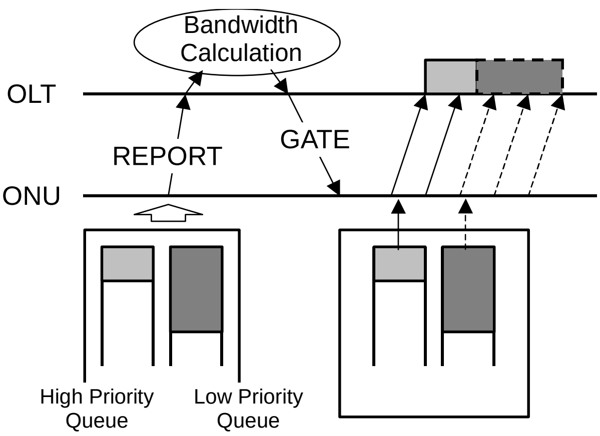

Fig. 3 Bandwidth control mechanism using a single LLID

3. Multicast Distribution Technology

One of the important factors in the triple-play service with GE-PON will be video distribution using multicast technology. In addition to the LLID allocated to each ONU as introduced in Chapter 2, broadcast LLID defined for GE-PON allows all of the logical links to receive data. Broadcasting without frame-copying is enable to utilize the broadcast LLID. This method is called the SCB (Single Copy Broadcast) method and is used for multicast distribution based on the broadcast LLID as shown in Figure 4. In this case, frame filters above the RS layer should be implemented on the ONU as the multicast frame is distributed to all of the ONU.

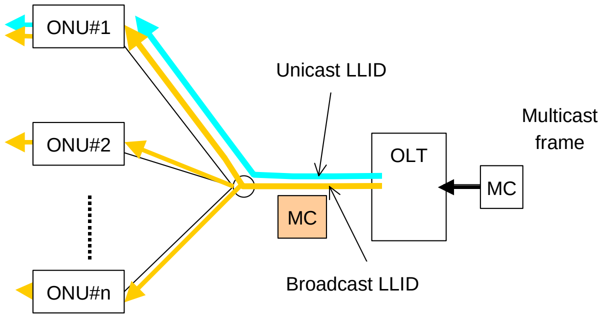

Fig. 4 SCB method

Notwithstanding the above, a certain means to efficiently and surely send frames to only the ONUs within the multicast group and a method to distribute encryption keys for multicasting is essential for the establishment of secure multicast distribution.

Multicast distribution requires filters to be installed on the ONUs so that only the ONUs within the multicast group receive the broadcast frames forwarded to all of the ONUs. For this particular purpose, we propose a method of group identification that combines the group control information with encryption technology. The encryption keys for multicasting are generated on the basis of the group control information by the OLT and shared by multiple ONUs that belong to a certain group. Any ONUs without the key cannot decrypt the data. In other words, multicast frames encrypted by means of the key are filtered at the ONUs which are not included in the multicast group. When the delivered frames are encrypted in this manner, the encryption function can also serve as identifiers.

It must be noted, however, that encryption keys in the case of applying the encryption method to multicast communication should preferably be generated and delivered to ONUs by the OLT as shown in Figure 5, because the group control is executed on the OLT. Furthermore, use of a different encryption key (such as an encryption key for the existing unicast distribution) for the encryption of the encryption key information for multicast, as shown in Figure 6, can provide a safe means of communication with the ONUs.

In this way, efficient and secure multicast distribution systems can be realized by combining the SCB technology, which is one of the features of PON, with encryption technology and the group control method.

With the recent remarkable progress in the information infrastructure, optical access service strategies based on the GE-PON for FTTH implementation are increasingly being introduced. Mitsubishi will continue to develop technologies for GE-PON systems to contribute to the use of FTTH in the future.

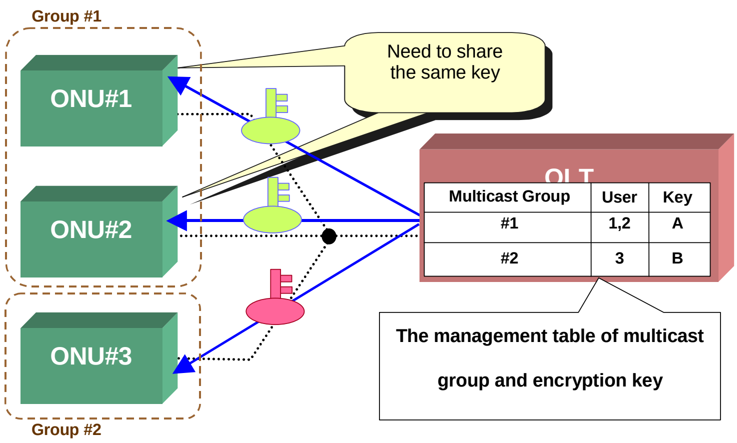

Fig. 5 Encryption key for multicast

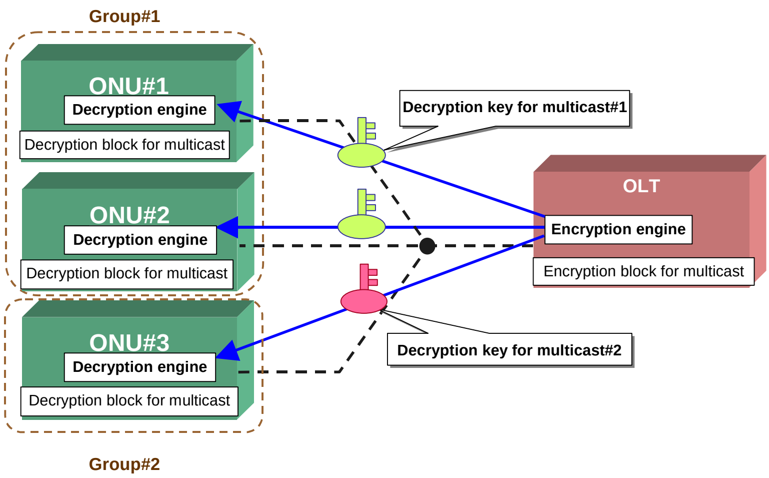

Fig. 6 Delivery method of encryption key for multicast

B-PON Interoperability and ONU Development

Authors: *Hiroyuki Ueda** and *Tetsuya Yokotani***

The PON (Passive Optical Network) is expected to become a mainstream technology for FTTH (Fiber To The Home), since it can reduce the number of fiber optic cables in the system configuration. The PON was originally standardized by ITU-T SG15WP1/Q2 and its group FSAN (Full Service Access Network); the B-PON (Broadband PON) system was established as ITU-T G.983 series. However, the issue was the interoperability between the OLT (Optical Line Terminal) and the ONU (Optical Network Unit) of different vendors. Detailed specifications must be clearly defined, including "ranging" that refers to the ONU connection protocol and procedures much more complicated than the conventional point-to-point communication systems. In order to deal with the problem, the ITU-T/FSAN planned to establish specifications for interoperability and to conduct official connection tests.

This paper outlines the verification for B-PON interoperability conducted by the ITU-T/FSAN. The paper also discusses Mitsubishi Electric Corporation's achievements in interoperability technologies for the development and standardization of PON-related products and an actual Mitsubishi ONU that meets the established interoperability specifications. [1]

1. Status of Interoperability Verification

The ITU-T/FSAN has continuously improved documents on the recommendations for the verification of interoperability and promoted commercial-system experiments with reference machines employed. The details are described in an independent report [2]; this chapter outlines the verification and efforts of Mitsubishi Electric Corporation.

1.1 Preparation of documents (recommendations)

For realizing reliable interoperability, FSAN issued three types of documents (recommendations): (1) G.983.1 Implementers' Guide, (2) PICS (Protocol Implement Conformance Statement), and (3) Test Suite [3]. Mitsubishi Electric Corporation, in cooperation with the carriers and vendors which have taken part in the FSAN, concluded (1) and (2) above, and the documents have been approved by the ITU-T.

In document (1), ITU-T G.983.1, which specifies the basic control of PON, was defined in detail, with the message sequence for the ranging clearly specified as shown in Figure 1 for example. In addition, emphasis is placed on the descriptions related with the operation, administration, and maintenance to present complementary explanation and assist the clarification of the standard. The contents have already been adopted into the recommendation.

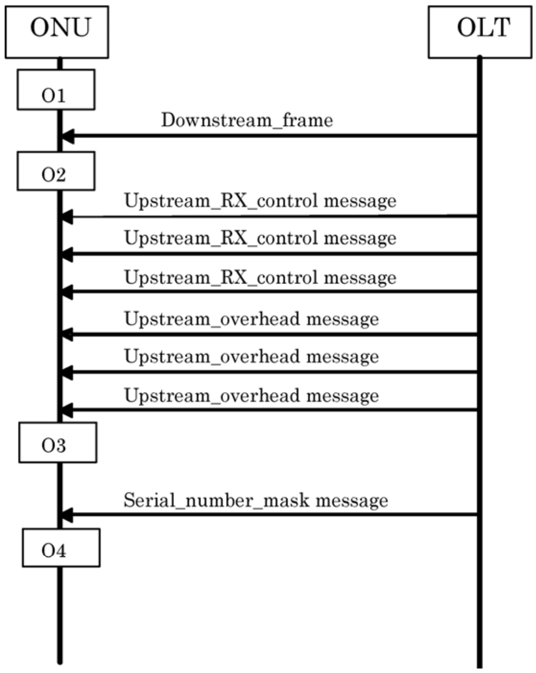

Fig. 1 Example for message sequence of ranging

In document (2), the items to be met by the units (OLT and ONU) in the interoperability between them are specified. This document has made it easier to confirm the conformance with the standard during the unit development phase. This document has been approved by the ITU-T as G. 983.1 Amendment. The front cover of the PICS is shown in Figure 2.

As for document (3), specifications and configurations of tests to be conducted for the verification of interoperability are specified.

1.2 Verification on commercial systems

The ITU-T/FSAN, along with the work in 1.1 above, has promoted interoperability tests using actual products of different vendors and verified the interoperability with respect to the PON control basic functions

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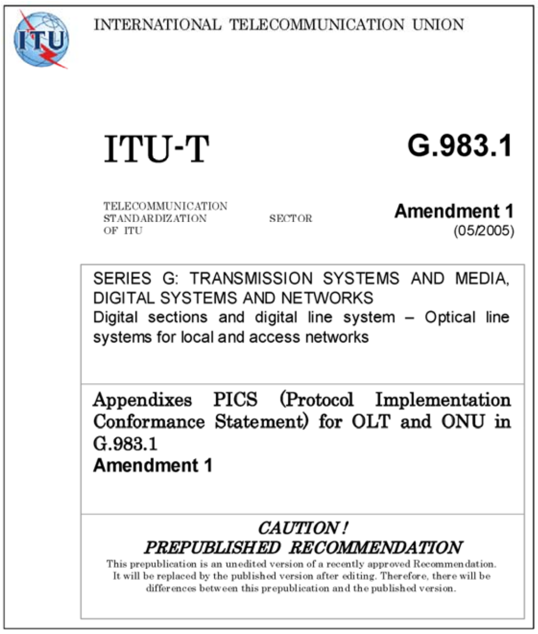
INTERNATIONAL TELECOMMUNICATION UNION

ITU-T

TELECOMMUNICATION STANDARDIZATION SECTOR OF ITU

G.983.1

Amendment 1
(05/2005)

SERIES G: TRANSMISSION SYSTEMS AND MEDIA, DIGITAL SYSTEMS AND NETWORKS
Digital sections and digital line system – Optical line systems for local and access networks

Appendixes PICS (Protocol Implementation Conformance Statement) for OLT and ONU in G.983.1
Amendment 1

CAUTION !
PREPUBLISHED RECOMMENDATION
This prepublication is an unedited version of a recently approved Recommendation. It will be replaced by the published version after editing. Therefore, there will be differences between this prepublication and the published version.

Fig. 2 The cover of G.983.1 Amendment 1

specified in ITU-T G.983.1. The details are described in the report [2]. Commercial-unit verification tests on three separate occasions have been conducted as shown below.

Test at Makuhari in March 2004 (with the participation of 9 vendors)

Test at San Ramon in September 2004 (with the participation of 6 vendors)

Test at Geneva in October 2004 (with the participation of 8 vendors)

2. Demonstration of Interoperability

The demonstration of interoperability was exhibited at "SuperComm" (Chicago, the U.S.) in June 2005 with the participation of 27 vendors, partly for publicizing the results of the verification tests of the interoperability mentioned above. Figure 3 shows the example structure in the demonstration. On this particular occasion Mitsubishi Electric Corporation also exhibited ONU products conforming to the recommendation and demonstrated the interoperability of two OLTs of two different vendors.

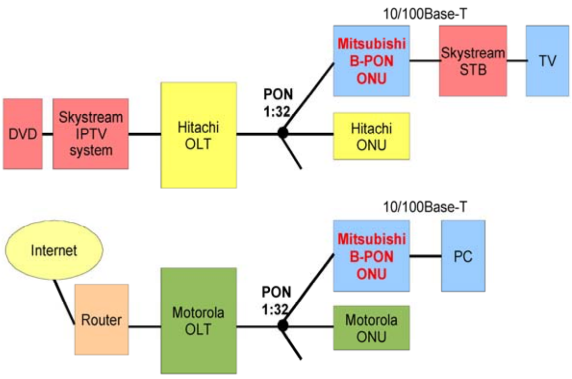

Fig. 3 The structure of the demonstration

3. Outline of Mitsubishi B-PON-ONU

3.1 Features of the unit

Mitsubishi developed commercial-use B-PON-ONU conforming to the interoperability specifications earlier than other vendors through the verification of interoperability as discussed above. Figure 4 shows the Mitsubishi B-PON-ONU. The unit has the following features.

Fig. 4 The Mitsubishi B-PON-ONU

(1) The unit conforms to the interoperability specifications (ITU-T G.983 series).
(2) The unit is designed to be compact and light (750 cc and 270 g).
(3) The unit is energy-efficient, consuming less than 5 W or less at a speed as high as 100 Mbps.
(4) The unit is easy to install, including mounting of fiber optics without the use of screws.

3.2 Configuration of unit

The interoperability in the system certainly requires conformity with the physical interface, compatibility with respect to the message sequence, and elimination of differences in the recognition of control messages from the OLT. The unit described below has achieved the required performance in accordance with the interoperability specifications. Figure 5 shows the structure of the B-PON-ONU.

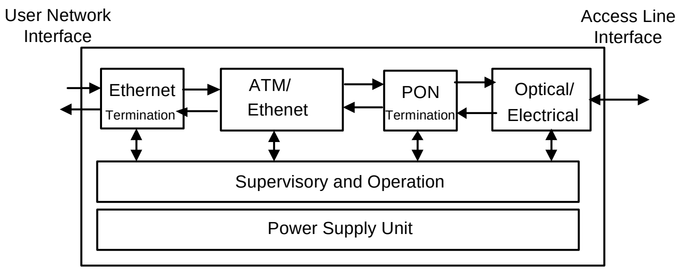

Fig. 5 The structure of B-PON-ONU

This paper introduced the outline of the efforts related with interoperability of B-PON which is one of the major technologies required for FTTH and Mitsubishi Electric Corporation's achievements. Further studies on interoperability and the like for the service level of the system are now required.

References

[1] M. Nakamura, H. Ueda, S. Makino, T. Yokotani, K. Oshima, "Proposal of networking by PON technologies for full and Ethernet services in FTTx", IEEE J. of Lightwave Technology, Vol. 22, No. 11, pp. 2631-2640

[2] T. Yoshida, International standardization activities for PON Conformance & Interoperability – From producing B-PON/G-PON international standard recommendations to the Conformance & Interoperability Certification – The Institute of Electronics, Information and Communication Engineers, Technical Report of IEICE, CS2005-26

[3] ITU-T Recommendation G983.1, "Broadband optical access systems based on Passive Optical Networks (PON)"

Optical Transceiver for Optical Access Systems

Authors: *Masamichi Nogami** and *Junichi Nakagawa**

In recent years, as a way of economically realizing a high-speed, large-capacity optical subscriber network, the commercial introduction of 1.25-Gbps GE-PON (Gigabit Ethernet-Passive Optical Network) systems has been expanding. In the case of a GE-PON system, individual subscribers (or ONUs: Optical Network Units) are geographically located at varying distances from an optical star coupler, so packets that reach a given station-side OLT (Optical Line Terminal) from such individual ONUs vary in intensity. Therefore, the optical receivers used in the OLT must be able to instantaneously reproduce packets of varying light intensity. On the other hand, the optical transmitter of an ONU must be able to instantaneously emit a light packet at a signal (transmission) rate of 1.25 Gbps. In this paper, we describe an optical transmitter, optical receiver and optical transceiver which we have developed for use in GE-PON OLTs and ONUs, all of which comply with the international standard IEEE802.3ah and which attain satisfactory performance characteristics.

1. GE-PON System Overview

Figure 1 shows the topology of a GE-PON system in which a single OLT is connected with multiple ONUs by a star coupler. Since this structure enables shared use of most of the optical fibers serving as transmission paths to connect the multiple ONUs and the (single) OLT, the operating cost is expected to be lower.

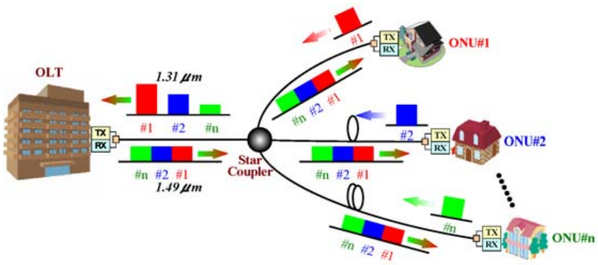

Fig. 1 Topology of GE-PON system

Regarding downstream traffic from the OLT to ONUs, each ONU extracts data from time slots that are allocated to it by means of a multicasting service method using the 1.49-μm wavelength band. On the other hand, for upstream traffic from the individual ONUs to the OLT, the 1.31-μm wavelength band and a time division multiplex method is used to control transmission timing so as to avoid collisions of data from the individual ONUs. Since these ONUs are located at geographically varying distances from the optical star coupler and so the optical intensity of individual ONU-launched traffic vary from packet to packet received at the OLT, the receiving circuitry of the OLT is required to stably reproduce packets of varying intensity.

2. OLT Optical Transceiver

2.1 Configuration of the OLT Optical Transceiver

Figure 2 shows a simplified block diagram of the OLT optical transceiver.

The optical transmitter consists of a high-output-power DFB-LD (Distributed Feedback-Laser Diode) with a wavelength of 1.49 μm and a driver IC and is equipped with an APC (Automatic Power Control) circuit, a signal degradation alarm-issuing feature and a shutdown capability.

The optical receiver consists of an APD (Avalanche Photodiode), a preamplifier capable of handling burst signals, a limiting amplifier equipped with an ATC (Automatic Threshold Control) function, and an APD bias voltage supply circuit. It operates on a reset signal-free basis. A preamplifier IC and a limiting amplifier IC have been newly developed using a 0.32-μm SiGe BICMOS process to be compliant with the IEEE802.3ah standard.

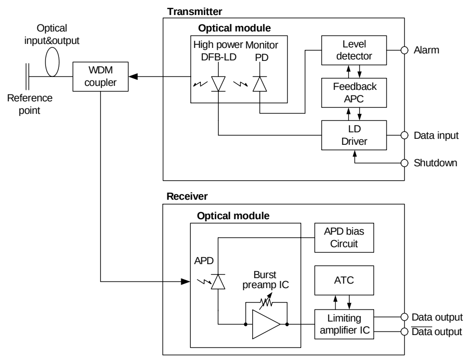

Fig. 2 Block diagram of the OLT optical transceiver

Figure 3 shows external views of the optical transmitter and the optical receiver of the OLT. The optical transmitter measures 32.4 mm by 20 mm by 11 mm, operates on a power supply voltage of 3.3V ± 5% and consumes power of less than 0.76 W. The optical receiver measures 46.3 mm by 30.6 mm by 12.7 mm, operates on a power supply voltage of 3.3V ± 5% and

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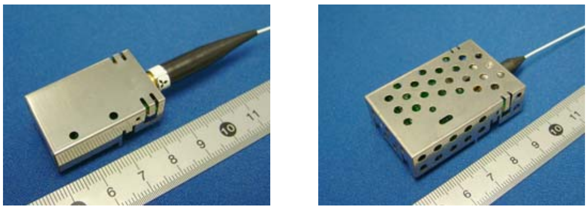
consumes power of less than 0.87 W.



(a) Transmitter (b) Receiver

Fig. 3 Photograph of OLT transmitter and receiver

2.2 OLT Optical Transmitter Characteristic

Figure 4 shows an optical output waveform after the signal has passed through a fourth-order Bessel-Thomson filter with a cutoff frequency of 937 MHz. Favorable waveforms measuring +4.0 dBm or greater in average optical output power, 17 dB or greater in extinction ratio and 65% or greater in mask margin were obtained at ambient temperatures from 0°C to 70°C. The transmission penalty after transmission through 20 km of single-mode fiber (SMF) (total dispersion: 317 ps/nm) was 0.1 dB or smaller.

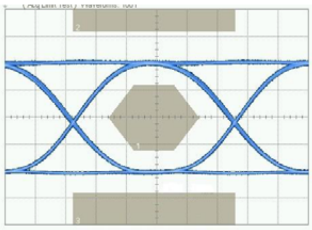


Fig. 4 Output waveform of OLT with fourth-order Bessel-Thomson filter

2.3 OLT Optical Receiver Performance

Since the OLT optical receiver for the PON system must stably reproduce burst signals of varying levels from each ONU at high speed, the receiver must have wide dynamic-range performance. As a burst-capable preamplifier gain control method, we adopted a continuous AGC scheme.

Figure 5 shows the bit error ratio performance at the time of burst reception. As the measurement method, with the average optical output power of the first packet fixed at –6 dBm, the bit error ratio performance of the second packet's data region (PN-7) was evaluated by varying the average optical output power of the second packet. At ambient temperatures from –5°C to 75°C, a bit error ratio performance of 1 x 10^{-12} or smaller was obtained over a reception optical level range of –30.1 dBm to –5 dBm, comfortably complying with the IEEE802.3ah standard.

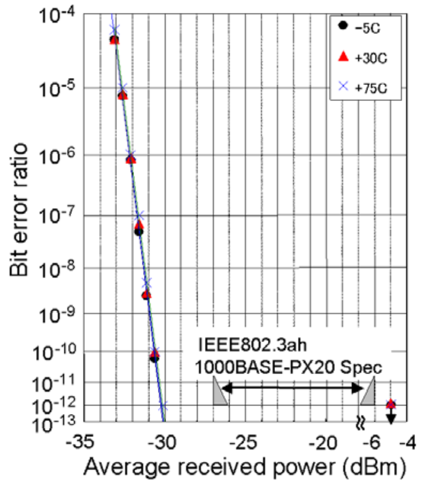


Fig. 5 Measured bit error ratio performance of OLT

3. ONU Optical Transceiver

3.1 Configuration of the ONU Optical Transceiver

Since this ONU optical transceiver is an optical interface to be installed in subscriber terminal equipment, it is required to make burst transmissions in order to avoid collisions with packets transmitted by other ONUs.

Figure 6 shows a simplified block diagram of the ONU optical transceiver. It consists of the transmitter block, the receiver block and the interactive wavelength multiplexing optical module which incorporates a light-emitting device (laser diode), a light-receiving device (photodiode), a preamplifier IC and wavelength selective combining and splitting devices in order to reduce size and cost. In addition, it also incorporates a rejection filter that works in the 1.55-µm band in preparation for future triple-play services carrying superimposed video signals.

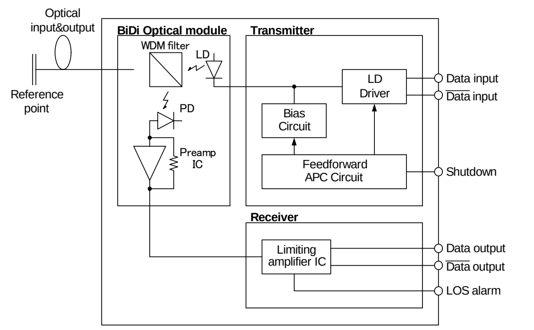


Fig. 6 Block diagram of ONU optical transceiver

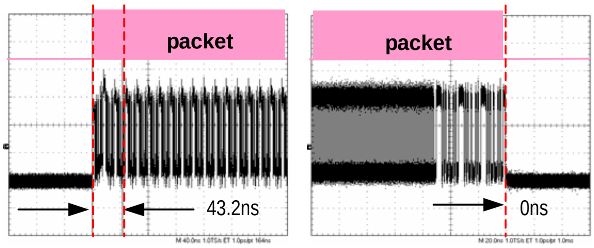
As for the light-emitting device in the transmitter block, an FP-LD (Fabry-Perot laser diode) is used for transmission through 10 km of SMF (single-mode fiber) (PX10) while a DFB-LD is used for transmission through 20 km of single-mode fiber (the PX20). For controlling the optical output power level, a feed-forward-type APC scheme is applied. A shutdown capability is also incorporated.

The receiver block consists of a PD (photodiode), a preamplifier, and a limiting amplifier and is equipped with a loss-of-signal alarm-issuing feature. Figure 7 shows an external view of the ONU optical transceiver. It measures 46.6 mm by 19.6 mm by 21.0 mm, operates on a power supply voltage of 3.3V ±5% and consumes power of 0.99 W or less.

Fig. 7 Photograph of ONU transceiver

3.2 ONU Optical Transmitter Performance

Favorable waveforms measuring +1.8 dBm or greater in average optical output power, 11.0 dB or greater in extinction ratio and 30% or greater in mask margin were obtained at ambient temperatures from 0°C to 70°C. Figure 8 shows optical output waveforms of the head and tail ends of a packet. During burst operation, the rise time is 43.2 ns or smaller and the fall time is 0 ns, both with adequate margins with respect to the value of 512 ns specified by IEEE802.3ah.



(a) Packet head end (b) Packet tail end

Fig. 8 Burst-on/burst-off time of packets

3.3 ONU Optical Receiver Characteristics

Figure 9 shows ONU bit error ratio performance. At ambient temperatures from 0°C to 70°C, a bit error ratio performance of 1 x 10^{-12} or smaller was obtained at a reception optical level of –28.5 dBm, comfortably complying with the IEEE802.3ah standard. Furthermore, the amount of deterioration caused by crosstalk due to operation on the transmitter side has been reduced to 0.2 dB or less by optimizing the structural and parts-mounting design.

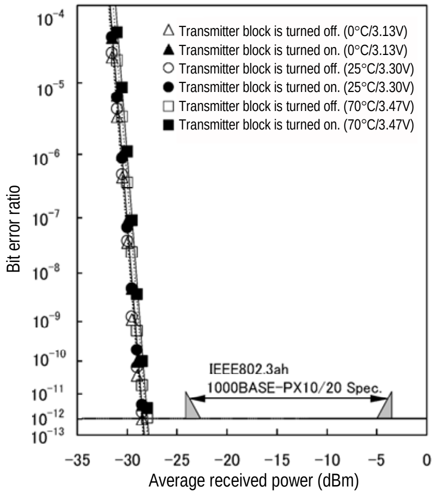


Fig. 9 Measured bit error ratio performance of ONU

As discussed above, we have developed optical transceivers that satisfy the international IEEE802.3ah standard, for use in GE-PON OLTs and ONUs and demonstrated that they produce satisfactory performance. We will continue with research and development in order to offer faster yet less expensive products.

Optical Devices for Optical Access Network Systems

Authors: *Shinichi Kaneko** and *Hideki Haneda**

Our newly-developed OLT optical transmitter module offers high optical output power over a wide range of operating temperatures by using a DFB laser that operates over a wide temperature range and by applying highly efficient optical system using an aspherical lens. The OLT receiver module achieves high sensitivity thanks to a high-responsivity APD and a low-noise pre-amplifier IC.

In addition, the cost of our newly-developed ONU optical transmitter device has been reduced by using a lens-equipped cap.

1. Optical Devices for Optical Access

1.1 DFB Laser

For optical transmitter devices in OLTs (Optical Line Terminals), narrow-spectral-width and high-output-power light sources lasing in the 1.49-μm band are required. We therefore apply a DFB (Distributed-Feedback) laser which is capable of selective single-mode lasing with the help of a grating close to the active regions. The device employs an FSBH (Facet Selective-growth Buried Hetero) structure with MQW (Multiple Quantum Well) active regions. Since the lasers with this structure exhibit high efficiency over a wide temperature range, this device structure is particularly useful for PON (Passive Optical Network) systems. Figure 1 shows the I-L curve of the DFB laser. As device characteristics, the laser features a low threshold current, a wide operating temperature range, a high side-mode suppression ratio (of 40 dB typical), and high-speed response (0.12 ns rise and fall time (20% – 80%)). A reliability of 100,000 hours or more is secured under actual usage conditions.

1.2 FP Laser

In the case of optical transmitter devices for ONUs (Optical Network Units), lens-capped FP (Fabry-Perot) lasers are used to reduce the cost of optical modules. For PON systems, since the ONU transmitter also needs high optical output power, we increased the output power of the FP laser. To increase the optical output power launched from the front facet of the laser, we optimized the FP laser design and achieved an efficiency of 0.45 W/A and an optical output power of 20 mW at 25°C. Figure 2 shows the I-L curve of our FP laser. Furthermore, we reduced the capacitance of the device to permit high-speed modulation at 1.25 Gbps.

We also improved the lens to increase the coupled optical power. In the case of bi-directional modules that are used in subscribers, optical couplings are often made by means of lenses that are attached to lasers. By using a high-refractive-index lens, high optical coupling efficiency of 20% can be achieved, and this has been further increased to 28% by introducing a low-aberration lens. Owing to these improvements, a high-coupling-efficiency LD (laser diode) module using an inexpensive lens has become possible.

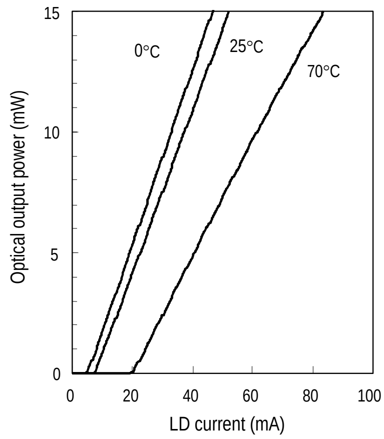


Fig. 1 I-L curve of DFB-LD used in OLT equipment

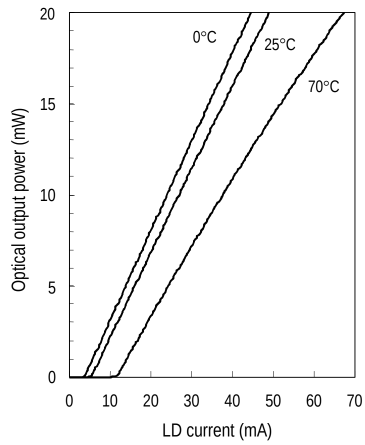


Fig. 2 I-L curve of FP-LD used in ONU equipment

1.3 APD

High-responsivity APDs (Avalanche Photo Diodes) are used in optical receiver devices for OLTs because the intensity of light incident on them has come down due to optical branching loss. When the APD is biased

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near its breakdown voltage, photocurrent amplification action takes place, making it possible to obtain a large photocurrent. We adopted InGaAs which has sufficient responsivity in the wavelength range from 1.0 μm to 1.6 μm for the absorption region and employed an InGaAs-InP planar structure which applies InP for the avalanche region. For reference, the active diameter of the APD is 35 μm. The APD's responsivity is 0.9 A/W at a wavelength of 1.31 μm and frequency bandwidth is 2.5 GHz, thus the APD is suitable for GE (Gigabit Ethernet)-PON systems. Figure 3 shows the I-V curve of the APD. The breakdown voltage is 60 V, and a multiplication factor of 10 or greater at an incident optical power of 0.3 μW is obtained.

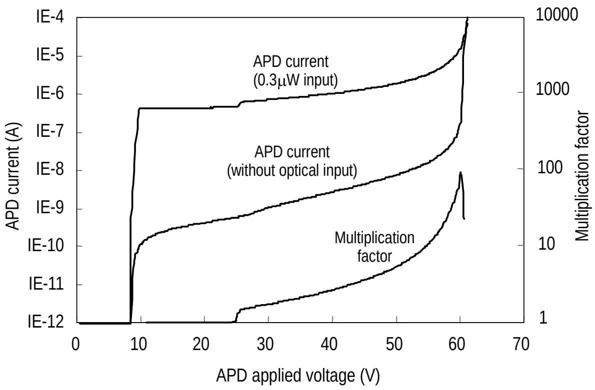

Fig. 3 I-V curve and multiplication factor of APD

2. Optical Modules for Optical Access

This section introduces our high-output-power optical transmitter module (or LD module) and high-responsivity optical receiver module (or pre-amplifier IC-embedded APD module), both to be installed into OLT transceiver equipment. Figure 4 shows a photograph of both modules.

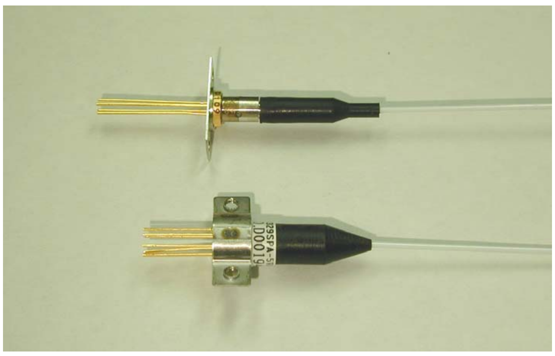

Fig. 4 Photographs of optical modules

2.1 LD Module

Figure 5 shows the internal structure of the LD module. We adopted a coaxial structure which is easy to mass-produce and reliable, yet low in cost. The 1.49-μm high-efficiency DFB laser discussed in the preceding section is used. With the help of an aspherical lens that has an excellent optical coupling property, a high optical coupling efficiency of about 65% is achieved. A monitor PD (photo diode) is mounted at the back of the DFB laser in order to detect optical output power from the DFB laser and to control the DFB laser so as to keep optical output power constant in case of the laser temperature change. On the other hand, an optical isolator is employed to suppress the generation of noise from the DFB laser due to optical feedback. The size and cost of the optical isolator have been reduced by mounting it on the optical input end of the optical fiber where the diameter of the beam launched from the DFB laser becomes minimum.

2.2 Pre-amplifier IC-embedded APD Module

Figure 5 shows the internal structure of the pre-amplifier IC-embedded APD module. We adopted a coaxial structure as in the case of the LD module. This module includes the high-responsivity APD discussed in the preceding section and our newly-developed low-noise burst pre-amplifier IC [1, 2] which is responsive to weak signals received by the APD and outputting the amplified signals. Because the APD has large active diameter, an optical coupling efficiency of almost 100% is achieved and the optical alignment is simplified. Since the pre-amplifier IC is required to instantaneously respond to various signal levels being sent from each subscriber, it uses a continuous AGC (Auto Gain Control) scheme which is designed to continuously vary conversion gain according to the signal levels. Owing to the high-responsivity APD and low-noise pre-amplifier IC employing the continuous AGC scheme, a high sensivity of –30.1 dBm is achieved even under the worst conditions where a signal of a large level of –6 dBm is followed by a burst signal of a small level. [2]

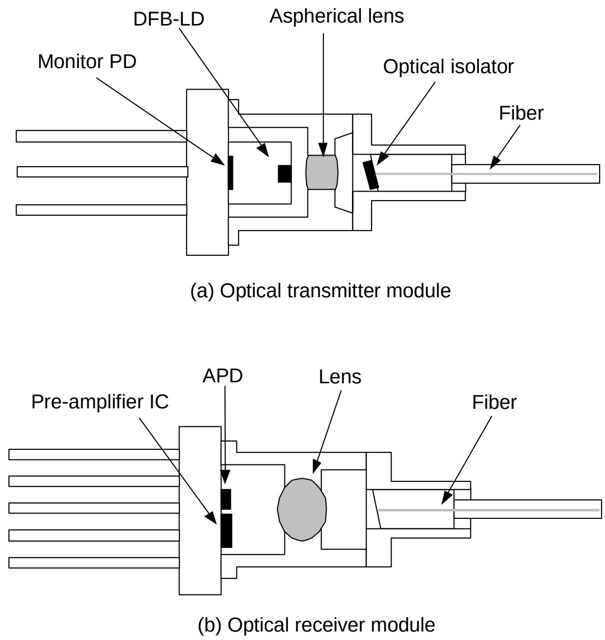

Fig. 5 Schematic structures of optical modules

References

[1] Masaki Noda, et al. “Development of IEEE802.3ah-compliant GE-PON OLT optical transceiver”, IEICE Technical Report OCS2004-75, 2004

[2] J. Nakagawa, et al., “Newly developed OLT optical transceiver for GE-PON systems compliant with IEEE802.3ah,” ECOC2004, We4. P.139

Operation System for Optical Access System

Authors: *Satoshi Ota** and *Toshimichi Kida**

We have developed an operation system for optical access system by combination of dedicated applications (collectively referred to as Exclusive Management Application, or EMA) and a general-purpose network management system, to enable large-scale and sophisticated management operations. This paper describes its features, and introduces the Java[1] Common Platform “M3” used on development of EMA.

1. Organization of the Operation System

As shown in Figure 1, the operation system for optical access system consists of the management server, management clients and external alarm equipment (status lights, made by PATLITE).

1.1 Management Server

(1) Performs management and control by communicating with optical access equipment, namely the nodes to be managed.
(2) Manages and controls the nodes by communicating with management clients and its upper-layer integrated management system.
(3) Controls external alarm equipment (i.e. turns on alarm lights/buzzers)
(4) To provide these server functions, a Hewlett-Packard general-purpose network management system, called OpenView Network Node Manager[2] (OV NNM) is combined with our proprietary EMA.
(5) Redundancy is achieved by using two workstation servers with HP clustering middleware, called MC/ServiceGuard[3].

1.2 Management Clients

(1) Provide GUIs (Graphical User Interfaces) for management and control.
(2) Manage and control nodes to be managed via the management server.
(3) Control external alarm equipment (i.e. turn off alarm lights/buzzers).
(4) To provide these client functions, HP’s OV NNM is combined with our proprietary EMA.
(5) Windows[4] PCs are used as management clients.

1.3 External Alarm Equipment

Under control from the management server and management clients, the external alarm equipment turns on/off lights and activates/deactivates buzzers.

2. Features and Technology of the Operation System

2.1 Sophistication of Management Operations

As shown in Figure 2, the operation system can handle sophisticated management tasks and special-purpose applications without compromising versatility, by the incorporation of our proprietary dedicated management applications into OV NNM.

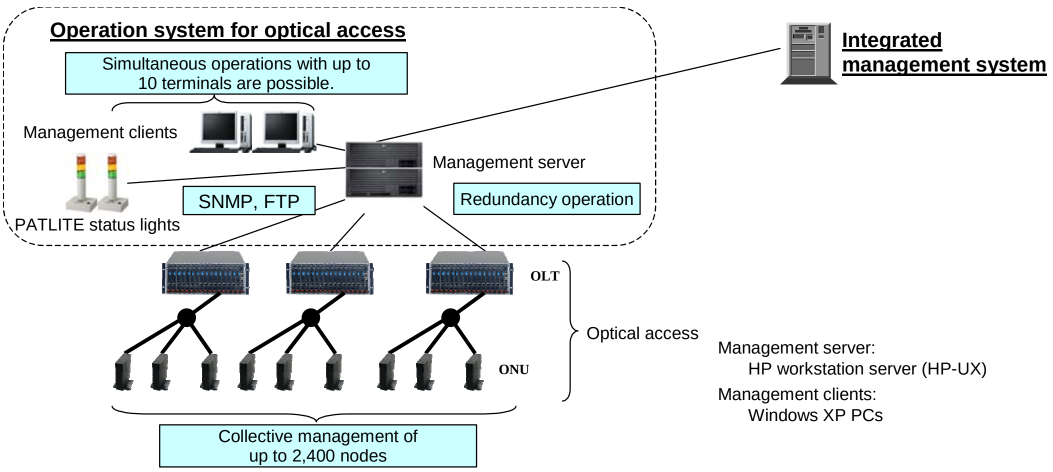

Fig. 1 Construction of operation system for optical access

[1] Java is a registered trademark of Sun Microsystems Inc.
[2] OpenView Network Node Manager is a registered trademark of Hewlett-Packard Company.
[3] MC/ServiceGuard is a registered trademark of Hewlett-Packard Company.
[4] Windows is a registered trademark of Microsoft Corporation.

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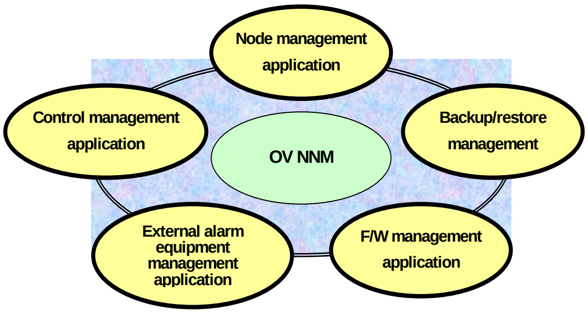

OV NNM: OpenView Network Node Manager

Fig. 2 Construction of applications

As illustrated in Figure 3, the roles are allocated among the intensive management by OV NNM, while the detailed management of individual nodes is done by our proprietary management applications.

2.2 Java Common Platform "M3"

For the operation system, we developed the EMA on an all-Java Common Platform "M3" (Mitsubishi Management Module).

As shown in Figure 4, M3 is a common platform operation system featuring modularization of each of the following: a) GUI control, b) DB control, c) communication, d) interface with other systems, e) distributed control, and f) redundancy. During application development, only the "xx-specific management" application part needs to be created, and then combined with the common-platform modules. This approach allows various applications to be rolled out by changing the management application part alone like swapping cassettes, thus minimizing the development work.

Moreover, since the M3 platform is written entirely in Java, it facilitates decentralization of usage and load and is also transportable to other machines due to hardware obsolescence, thanks to its OS-independence.

2.3 Large-scale Management

This operation system for optical access system can collectively manage up to 2,400 nodes. Up to ten management clients can be connected to the management server, enabling simultaneous operations at multiple locations.

2.4 Management Control Interface

This operation system for optical access system manages nodes using SNMP and FTP, two general-purpose protocols.

For a upper-layer integrated management system, the operation system offers management control interfaces by means of SNMP, CORBA and FTP (file I/F). These capabilities are implemented through add-ons to OV NNM or our proprietary management applications.

2.5 High Reliability

The management server ensures high reliability through clustering, disk mirroring and automatic backup technologies. An example of this configuration is shown in Figure 5.

A cluster is formed with two workstation servers through HP's MC/ServiceGuard clustering middleware. In the event of a server failure, switchover takes place automatically and management operation can continue without interruption.

Disk mirroring is accomplished with HP's Mirror Disk[5] which mirrors data across hard drives holding various databases.

The operation system also offers automatic backup of data to a tape drive. By regularly making backup copies of databases stored in hard drives, it is possible to quickly restore from backup tape when data corruption.

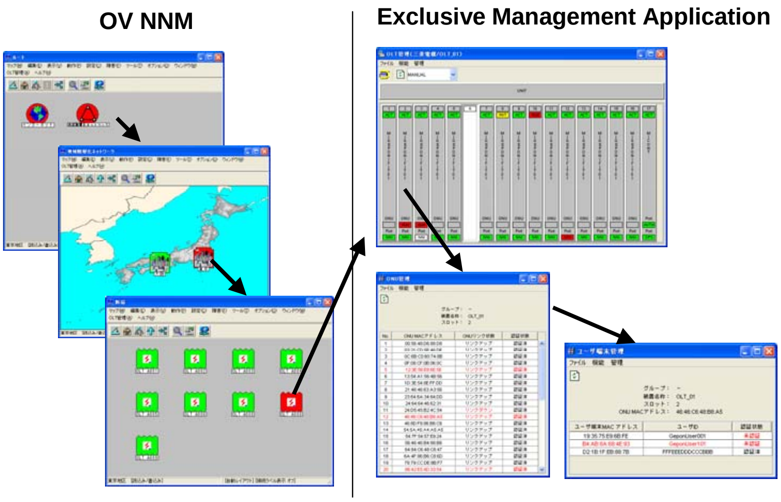

Fig. 3 Assignment of applications

[5] MirrorDisk is a registered trademark of Hewlett-Packard Company.

3. Conclusion

Operation systems are becoming more sophisticated and delivery times are shortening, so hybrid configurations such as the one described here are essential. We are continuing to enhance common-platform technologies and simplify the development of dedicated applications

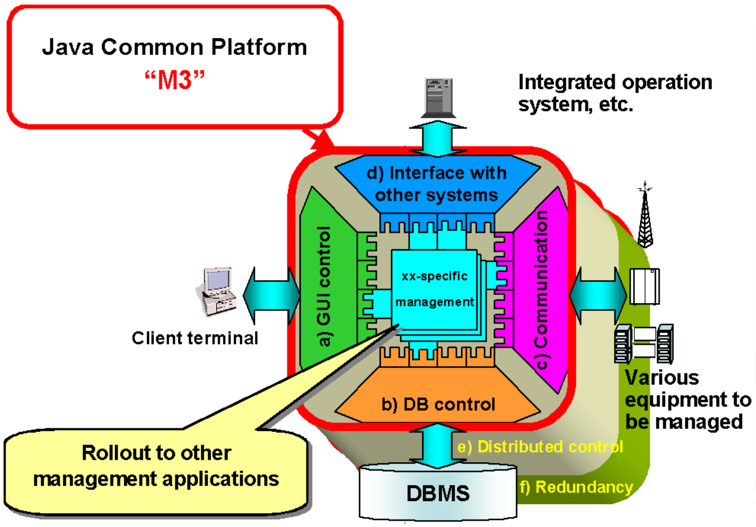

Fig. 4 Construction of Java common platform "M3"

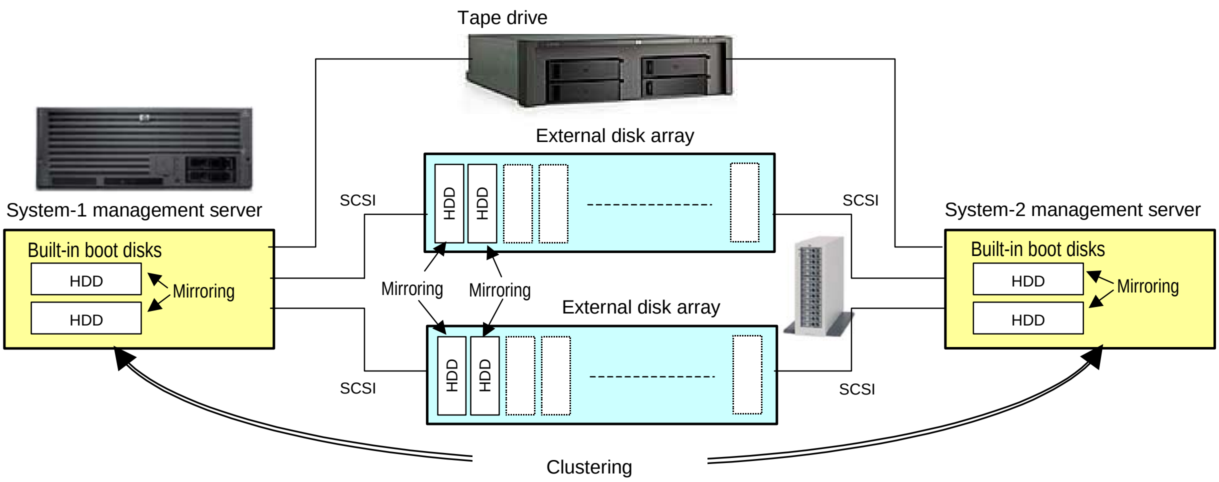

Fig. 5 Redundancy of operation system server

Next-generation Optical Access Systems

Authors: *Junichi Nakagawa** and *Katsuhiro Shimizu**

To keep up with the explosive demand for Internet access, the commercial introduction of GE-PON (Gigabit Ethernet Passive Optical Network) systems with a transmission rate of 1.25 Gb/s has been proceeding as a means of building cost-effective high-speed optical subscriber networks. To enhance the speed and capacity, focus is being placed on the research and development of next-generation PON systems such as WDM (Wavelength Division Multiplexing)-PON systems and 10G-PON systems. For next-generation PON systems, targets include the capturing of FTTH subscribers such as high-end users, business users and multifamily-housing users and the provision of bandwidth-guaranteed services and high-definition video services, among others. To accommodate such users and provide such services, WDM-PON systems using WDM technology that allow each user to occupy the bandwidth of a single wave and 10G-PON systems using TDM (Time Division Multiplexing) technology, which increases the transmission rate from the current 1 Gb/s to 10 Gb/s, hold promise. This paper introduces WDM-PON optical interface infrastructure technology and 10G-PON optical interface infrastructure technology as infrastructure technologies of next-generation PON systems.

1. WDM-PON Optical Interface Infrastructure Technology

Figure 1 shows a schematic diagram of a WDM-PON system configuration. A WDM-PON offers a variety of advantages such as the following:

(1) Permits the shared use of trunk fibers (each up to 50 km long) for reducing costs and eliminating the problem of fiber shortage.
(2) Economization through the simplification of equipment installed at accommodation stations.
(3) Since each subscriber occupies one wave for downstream traffic and another wave for upstream traffic, bandwidth can be guaranteed.

WDM-PONs present technical challenges such as (1) reducing the cost of equipment and (2) making the ONUs (Optical Network Units) colorless (or wavelength-independent).

To achieve both of these challenges, a method whereby upward carrier light is distributed from the OLT (Optical Line Terminal) side and signals are superimposed onto carrier light by ONUs is being studied. As a key device to realize such ONUs, we have worked on developing a hybrid device that integrates semiconductor optical amplifiers (SOAs) and an electro-absorption (EA) modulator.

Figure 2 shows a schematic diagram of the SOA-EA-SOA integrated device that we have developed. The device consists of two semiconductor optical amplifiers and one EA modulator. The active layers of the SOA portions and the absorption layer of the EA portion are both designed to minimize polarization dependence. In addition, the isolation regions prevent high-speed modulation signals applied to the EA modulator from leaking into the SOA portions.

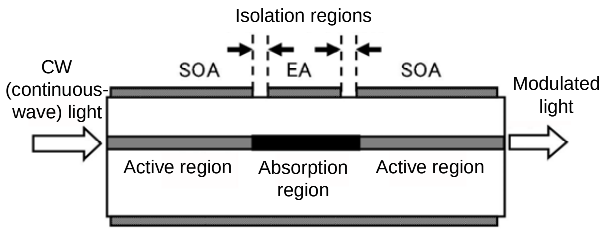

Fig. 2 Configuration of SOA-EA-SOA optical device

Figures 3 (a) and (b) show the optical output waveforms (at 1530 nm and 1560 nm) of the SOA-EA-SOA integrated device. In consideration of the application of soft-decision turbo FEC (Forward Error Correction), we set the modulation rate at 12.5 Gb/s. At wavelengths of 1530 to 1563 nm covering the entire C band, we could obtain distortion-free favorable eye patterns. When the

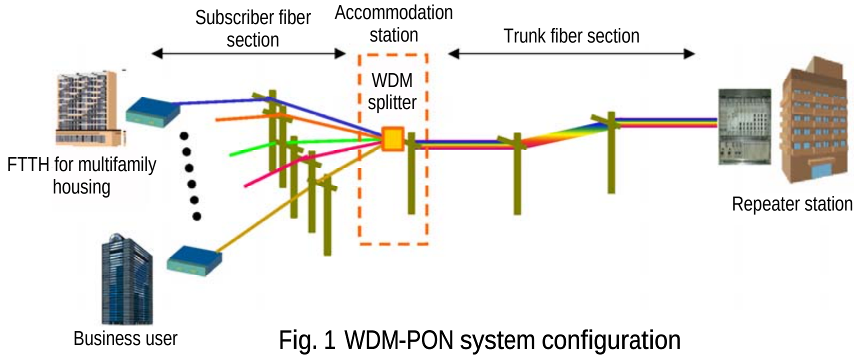

Fig. 1 WDM-PON system configuration

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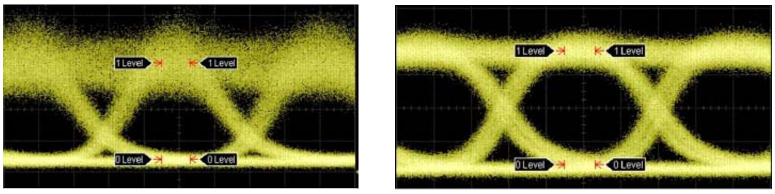

Fig. 3 12.5-Gb/s optical waveforms modulated by SOA-EAM-SOA

power of light incident on the incident-side SOA measured -20.0 dBm, we could obtain an extinction ratio of 8.3 to 9.4 dB and an optical output power of -1.8 to +1.1 dBm. Figure 4 shows the transmission characteristics achieved by using the SOA-EA-SOA integrated device. Considering the use of optical fiber amplifiers for repeater applications, we set the SNR (Signal-to-Noise Ratio) at 10 dB and measured the bit error rate after 0-km, 20-km and 40-km transmission through single-mode fiber (SMF).

Figure 4 shows that a bit error rate of 10^{-4} or smaller was obtained at an input level of -30 dBm or greater after 40-km transmission through SMF. This represents an excellent transmission characteristic where a bit error rate of 10^{-13} or less is obtained with the help of G.709-compliant FEC and a bit error rate of 10^{-13} or less is obtained by means of soft-decision turbo with a margin of 4 dB or greater.

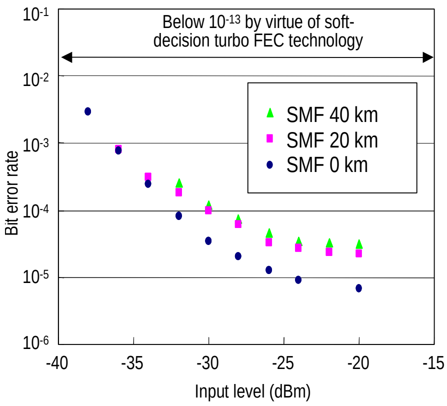

Fig. 4 Upstream bit error rate performance of WDM-PON

2. 10G-PON Optical Interface Infrastructure Technology

Figure 5 shows a schematic diagram of a 10G-PON system configuration. As with B-PONs and GE-PONs, 10G-PONs offer the following advantages:

(1) Cost can be reduced through commonality of OLT-side equipment and optical fiber.

(2) Low-priced services can be offered to business users and high-end users.

Therefore, as with a GE-PON, it is also possible with a 10G-PON to achieve a low per-user price by concentrating the functions on the OLT-side interface to gain the effects of shared use of multiple ONUs and by simplifying the ONU-side interface. The OLT-side transmitting-side interface consists of a semiconductor optical amplifier (SOA), an electro-absorption (EA) modulator-equipped DFB (Distributed Feedback) laser and an EA driver in order to achieve high output power and low dispersion penalty. The OLT-side light-receiving interface consists of a high-sensitivity APD preamplifier and a limiting amplifier for burst reception. Depending on the required power budget and transmission distance, it is also conceivable to apply an SOA to the OLT receiving-side interface as an optical preamplifier. Furthermore, regarding the ONU-side optical interface, we have decided to construct its transmitting side with a direct modulation DFB laser and a laser driver and its receiving side with a high-sensitivity PD preamplifier and a limiting amplifier in order to suppress the cost. In addition, we have adopted FEC technology.

Table 1 summarizes the target 10G-PON specifications. For the required power budget and transmission penalty, we have set target specifications that are equivalent to ITU-TG.984.2 Class B or IEEE802.3ah 100BASE-PX20.

Figure 6 shows optical output waveforms that are output by our optical transceiver developed as a 10G-PON optical interface. Figure 6 (a) shows an

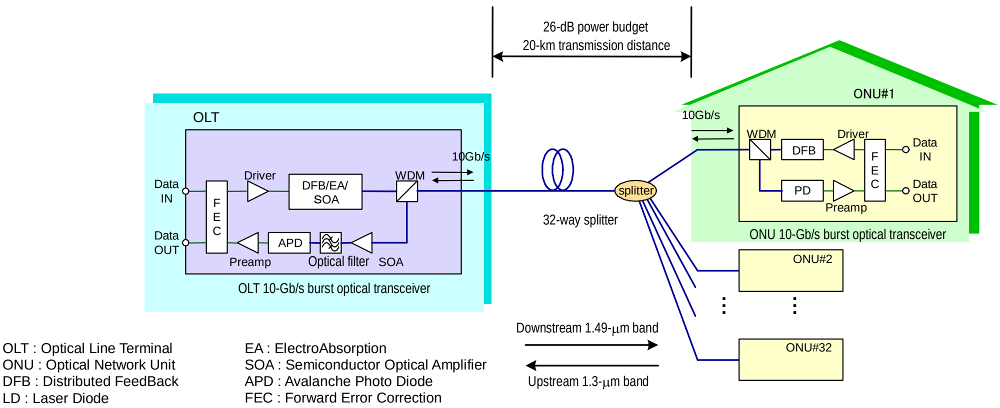

Fig. 5 10G-PON system configuration

OLT-derived optical output waveform after having passed through a fourth-order Bessel-Thomson filter while Figure 6 (b) shows an ONU-derived optical output waveform. We have newly developed an EA/LD module for long-haul applications which features a dispersion penalty of 2 dB or smaller after 80-km SMF transmission, and incorporated it into the OLT-side optical transceiver. On both OLT and ONU sides, favorable eye-pattern openings were obtained; OLT optical output power and extinction ratio measured 7.8 dBm and 11.0 dB, respectively, while ONU optical output power and extinction ratio measured +2.0 dBm and 6.3 dB, respectively.

Table 1 Target specifications of 10G-PON

Item	Target specification	Note
Power budget	26.0dB	• ITU-TG.984.2 Class B or equivalent • IEEE802.3ah 1000BASE-PX20 or equivalent
Transmission distance	SMF 20km	
Dispersion penalty	1.0dB	

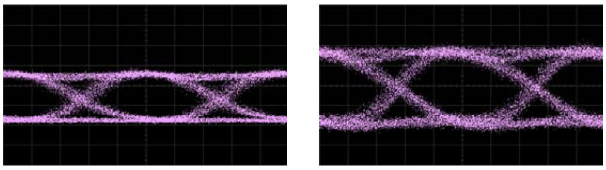

Fig. 6 Optical transmitted waveforms (a) OLT (b) ONU

Figure 7 shows optical output waveforms derived from the ONU-side optical interface during burst mode operation. We can see that 290-μs-long random signals and optical burst signals, each with a guard time of 100 μs, are being issued by two ONUs (ONU#A and ONU#B).

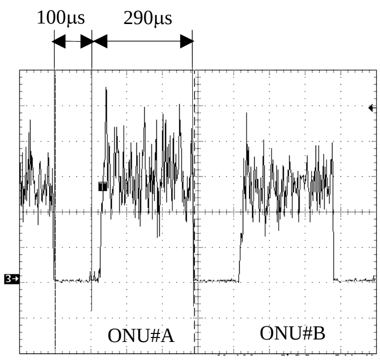

Fig. 7 Burst-mode optical waveforms

Figure 8(a) shows the results of downstream and back-to-back bit error rate measurements after 20-km SMF transmission while Figure 8(b) shows upstream and back-to-back bit error rate measurements after 20-km SMF transmission. The bit error rate measurements were done using a configuration made up of one OLT and two ONUs (ONU#A and ONU#B) with an OLT:ONU ratio of 1:2. Optical waveforms after 20-km SMF transmission are also shown in Figures 8(a) and 8(b). From Figure 8(a), we derive a minimum receiver sensitivity of -16.5 dBm (@ bit error rate = 10^{-12}, FEC = OFF), a minimum receiver sensitivity of -19.5 dBm (FEC = ON), and a transmission penalty of 0.6 dB in the downstream direction.

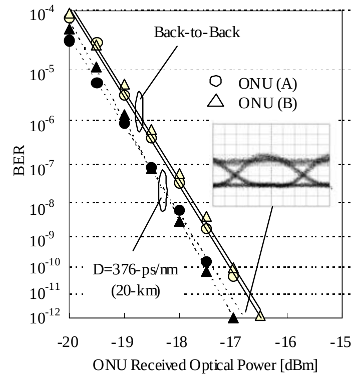

Fig. 8 (a) Bit error rate performance downstream

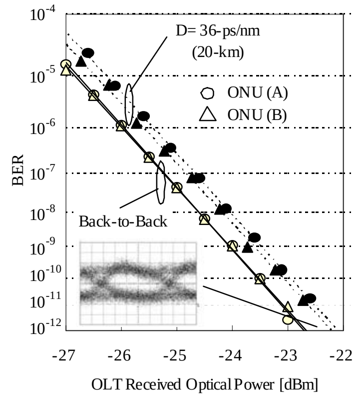

Fig. 8 (b) Bit error rate performance upstream

Table 2 summarizes the 10G-PON power budget and dispersion penalty results. When FEC is applied, a downstream power budget of 27.6 dB and upstream power budget of 28.8 dB can be obtained. Through verification of infrastructure optical device technologies in this study, we have shown that power budgets and dispersion penalties in compliance with ITU-T G.984.3 Class B and IEEE802.3a 100BASE-PX20 can be achieved.

Table 2 Evaluation results of 10G-PON

Item	Target specification	10G-PON prototyping results	
		Downstream	Upstream
Power budget (FEC ON)	26.0dB	27.5dB	29.3dB
Transmission distance	SMF 20km	SMF 20km	
Dispersion penalty	1.0dB	-0.5dB	0.6dB

3. Conclusion

As infrastructure technologies for next-generation PON systems, we have discussed WDM-PON optical interface infrastructure technologies and 10G-PON optical interface infrastructure technologies. For use in WDM-PON systems, we have developed an ONU-specific SOA-EA-SOA integrated device and obtained favorable optical waveforms and transmission characteristics using the device. For use in 10G-PON systems, we have worked on developing the optical interface and demonstrated that power budgets and dispersion penalties equivalent to ITU-T G.984.3 Class B and IEEE802.3ah 100BASE-PX20 are practical.

GE-PON Optical Network System

Author: *Hideki Bessho**

We have commercialized a GE-PON optical access system which is ideally suitable for common telecommunication carriers and CATV operators who provide high-speed broadband services over optical fiber.

We are offering a totally integrated system confirmed with an international standard IEEE802.3ah, consists of OLTs (Optical Line Terminals), ONUs (Optical Network Units),and an operation system. The system supports up to eight logical links for applying to multiple service, the traffic control mechanism, and priority control per subscriber make it possible to deliver optical based IP telephone service with clear audio quality, High definition video delivery, and high-speed Internet access realized with excellent reliability.

(1) The optical power budget has enhanced to 29 dB (i.e., improve 3 dB from IEEE standard), realized up to 64 optical splits over single fiber and 20km maximum reach. As a result, it can minimize the investment of the deployment, such as reducing the number of optical line terminal (OLT) equipment required and the laying optical fiber from central office, makes most economical optical access system ever.

(2) Newly developed various features, such as an expand VLAN (Virtual Local Area Network), priority control work with eight queues, IEEE802.1X-compliant terminal authentication functionality and strong encryption for assuring confidentiality. It makes the system beneficial for any various services.

(3) Each OLT can accommodate up to 16 PON interface cards, thus saving rack mount space through high-density design.

(4) Integrates the built-in blocking filter, easily supports the transmission of broadcast signals carried over expanded wavelength by means of single-core 3-wavelength multiplexing methodology.

(5) The operation system supports the Simple Network Management Protocol (SNMP) can realize easy access for operation and maintenance. Furthermore, the supporting redundant architecture ensures continuous, nonstop operation in the event of a failure by automatic.

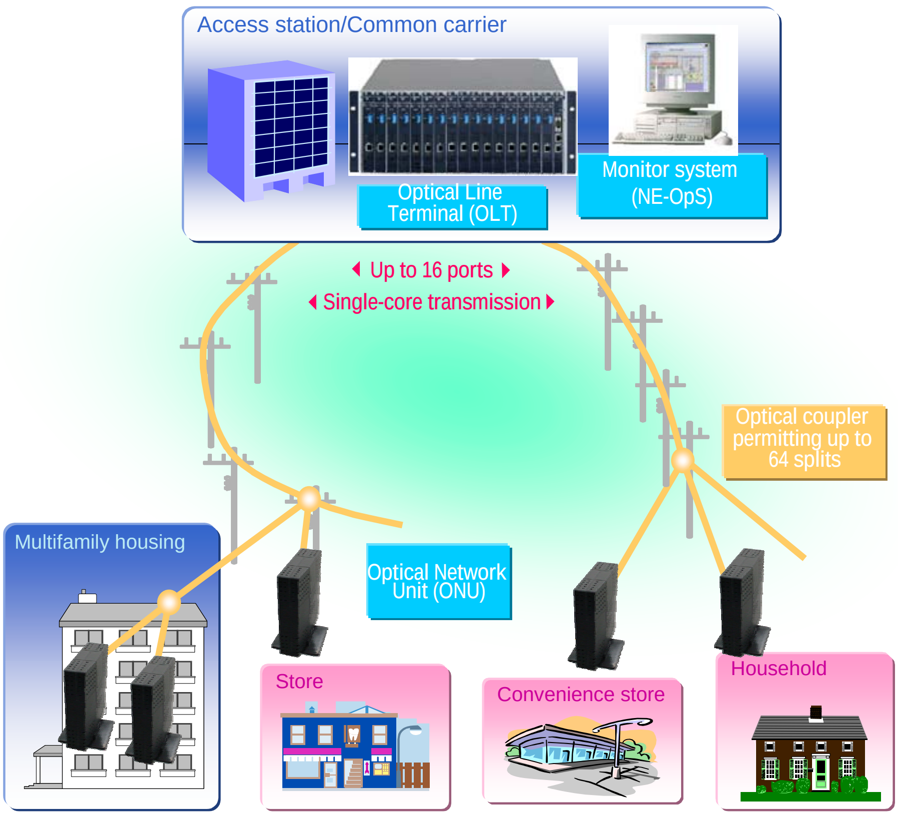

Fig. 1 Network diagram

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