Development of a Gigabit Ethernet Passive Optical Network (GE-PON) System

Koji Ochiai, Tsutomu Tatsuta†, Takashi Tanaka, Osamu Yoshihara, Noriyuki Oota, and Noriki Miki

Abstract

The gigabit Ethernet passive optical network (GE-PON) is a high-speed optical access method that has been standardized according to IEEE 802.3ah and is attracting attention as some operators have started to provide optical access service with it. NTT Access Network Service Systems Laboratories has developed a GE-PON system that should capture a major share of the FTTH (fiber to the home) market, which is expected to become very competitive in the near future.

1. FTTH market overview

Since 2001, point-to-point and passive optical network (PON) fiber to the home (FTTH) access systems have been widely deployed in Japan, in response to rapid growth of high-speed Internet access services and competition in both monthly access charges and transmission speed, driven by the popularity of ADSL (asymmetric digital subscriber line) access. Currently, besides conventional telecom operators, major power utility companies and ADSL service operators are also providing FTTH. The monthly rise in the number of FTTH users has reached 100,000 and the total number of FTTH subscribers exceeded 2 million in September 2004 [1].

2. Trend of PON systems

Network costs need to be reduced further in order to persuade more home users to use FTTH. The PON architecture lets operators make significant savings in fiber cost in the access network. It has been favored by telecom operators and some power utility companies for FTTH access to individual home users.

In Japan, a considerable number of PON systems deployed in the access network have been GE-PON since major operators announced the installation of GE-PON for residential FTTH access last year. Japanese operators prefer GE-PON because they are focusing on data transmission services [2].

3. Outline of the GE-PON standard

GE-PON was specified by the IEEE 802.3ah Ethernet in the First Mile (EFM) task force as one of the Ethernet interface series in June 2004 [3]. To provide a wide variety of broadband services and to allow for future capabilities, the 1000BASE-PX series was specified in the IEEE 802.3ah standard. 1000BASE-PX10 (up to 10 km) and 1000BASE-PX20 (up to 20 km) physical media dependents (PMDs) have been prepared for GE-PON. The wavelengths of optical signal transmission are based on ITU-T* G.983.3, so that additional services like video broadcasting using a wavelength of 1550 nm are possible. The maximum splitting is not specified by IEEE 802.3ah because it depends on PMDs and actual optical link losses. GE-PON provides 2 octets (16 bits) for the logical link identifier (LLID) and 15 bits can be assigned to each medium access control (MAC). Therefore, more than 30,000 optical network units (ONUs) can be logically accommodated in a PON.

A key feature of GE-PON is that data is transmitted

† NTT Access Network Service Systems Laboratories
Chiba-shi, 261-0023 Japan
E-mail: tatsuta@ansl.ntt.co.jp

* ITU-T: International Telecommunication Union Telecommunication Standardization Sector

in variable-length MAC frames of up to 1518 octets (1522 octets for a tagged frame). The downstream transmission is based on the original Ethernet mechanism keeping a minimum inter-frame gap of 12 octets. An optical line terminal (OLT) broadcasts MAC frames to every optical network unit (ONU) accommodated in a PON, so each ONU receives all the MAC frames. However, a two-octet frame-header called an LLID contains address information. As a result, only the addressed ONU reads its MAC frames; ONUs discard frames that are not addressed to them. On the other hand, upstream transmission is based on TDMA (time division multiple access) arbitration to avoid data collisions between ONUs. The OLT allocates a transmission window called a gate to each ONU. When an ONU receives the gate frame, it transmits MAC frames at a rate of 1 Gbit/s during the time slots assigned by the gate. Multipoint control protocol (MPCP) contains the gate allocation for each ONU, gate request from the ONU, and discovery and registration of ONUs with the PON.

4. Main specifications of NTT's GE-PON system

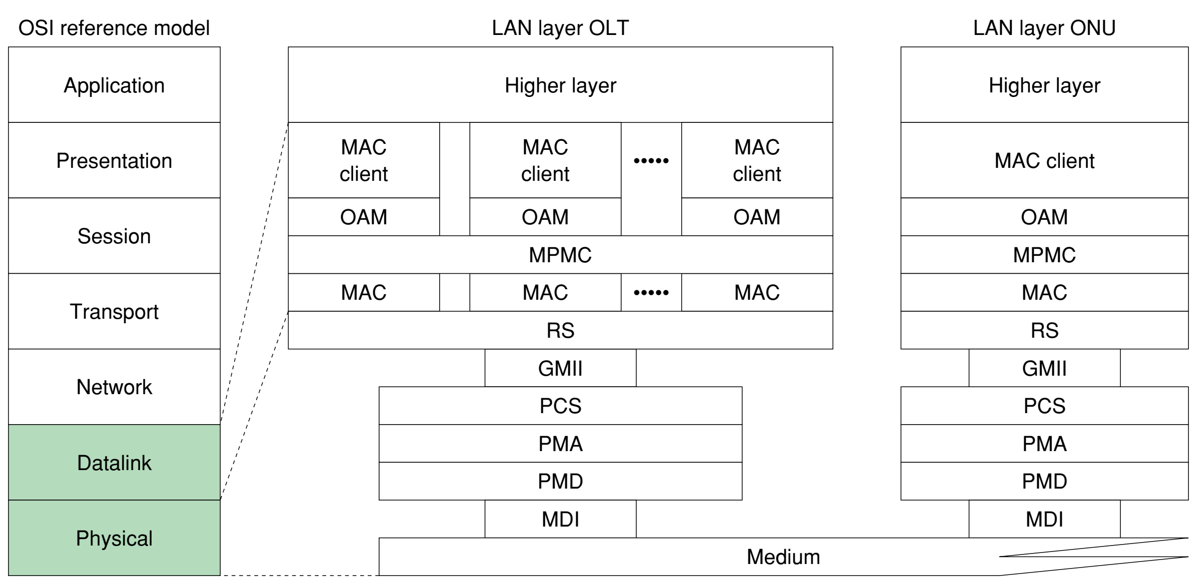
IEEE 802.3, which includes IEEE 802.3ah, specifies the data link and physical layers, but regards other specifications as out of its scope (**Fig. 1**). For instance, because there is no specification for how the system activates the MPCP, the GE-PON system cannot work only by referring to the IEEE 802.3 standard. During the design of a GE-PON as an access system, these specifications will be defined by referring to other standards, proprietary proposals, and operator's requirements.

We have developed our own set of specifications for optimizing the deployment of a GE-PON access system that includes interoperability between different vendors [4]. The construction of our GE-PON system is shown in **Fig. 2**, its function stack is shown in **Fig. 3**, and the external appearances of the ONU and OLT are shown in **Fig. 4**. The main specifications outside the IEEE 802.3ah standards are explained below.

4.1 Dynamic bandwidth allocation (DBA)

DBA is a function that allocates the upstream bandwidth to each ONU. As the features of the provided service depend on this function, we developed a DBA function that achieves a balance between high bandwidth efficiency and low delay [5].

In the GE-PON system, an upstream bandwidth of 1 Gbit/s is shared among up to 32 ONUs. One method of allocating the upstream bandwidth is to set the assigned bandwidth for each ONU to a fixed value (static allocation) regardless of the upstream traffic. However, since bandwidth is allocated to an ONU even when it has no upstream traffic, a lot of bandwidth is wasted. To eliminate this wastage, a DBA algorithm is installed in the OLT. The DBA algorithm



OAM: operation, administration and maintenance
MPMC: multipoint MAC control
RS: reconciliation sublayer
GMII: gigabit media independent interface
PCS: physical coding sublayer
PMA: physical medium attachment
PMD: physical medium dependent
MDI: medium-dependent interface

Fig. 1. GE-PON protocol stack.

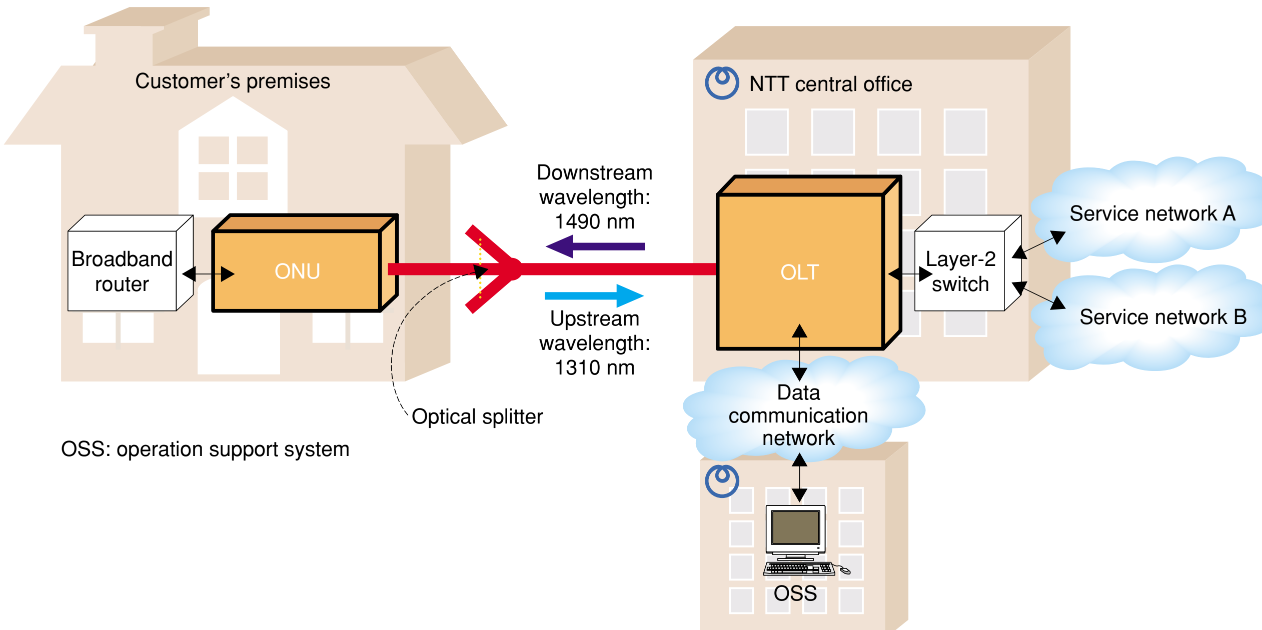


Fig. 2. System construction.

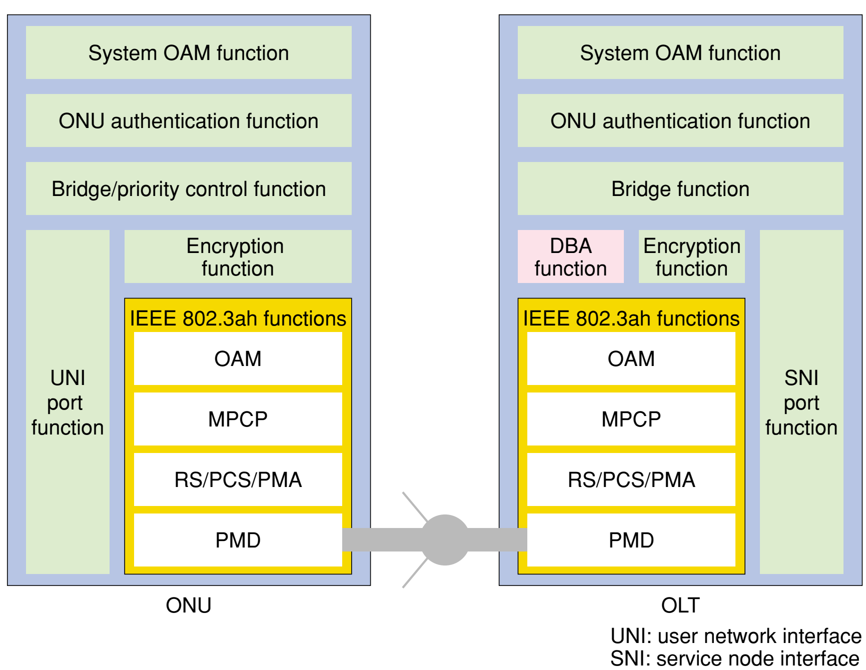


Fig. 3. Function stack.

flexibly allocates bandwidth according to the amount of upstream traffic. Therefore, unused bandwidth can be allocated to other ONUs, allowing the available bandwidth to be utilized more efficiently. As shown in **Fig. 5**, it is possible to share bandwidth evenly among the ONUs using the upstream bandwidth.

We developed a new DBA algorithm specifically for the GE-PON system. It is designed to pack variable-length Ethernet frames efficiently and leads to lower delay and higher bandwidth efficiency. Its features are described below.

(A) Bandwidth control

It is possible to configure the minimum guaranteed bandwidth and the maximum bandwidth of each ONU. The bandwidth is distributed to the ONUs in proportion to each ONU's minimum guar-

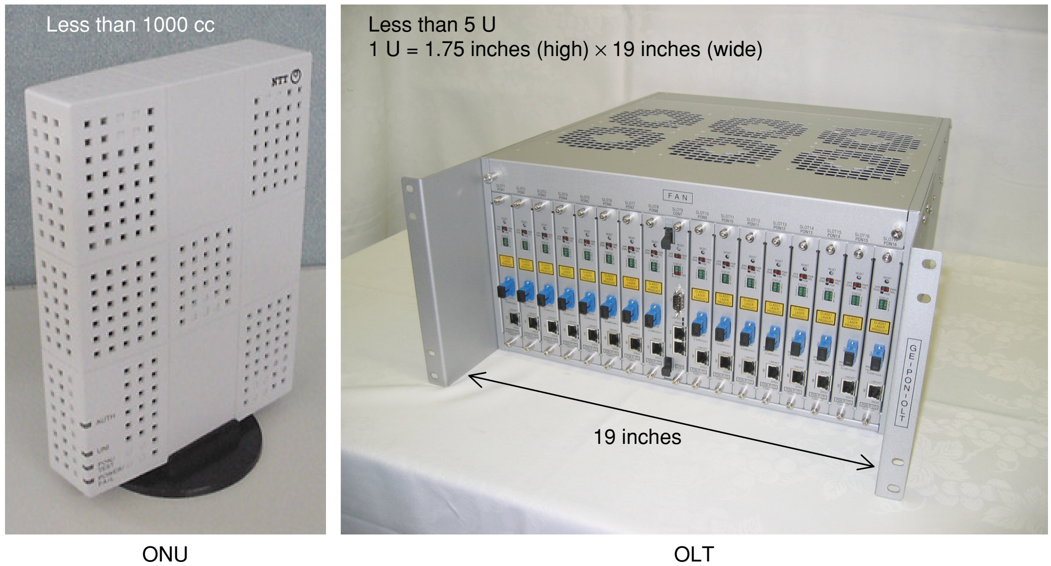


Fig. 4. External appearances of the ONU and OLT.

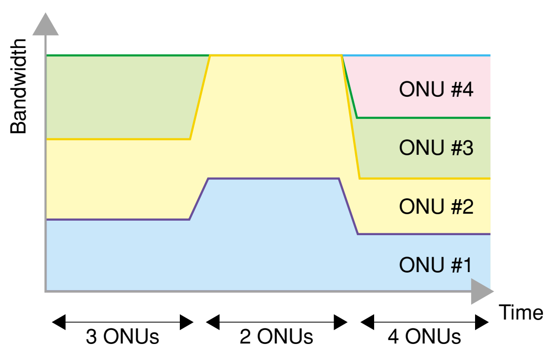


Fig. 5. Concept of DBA.

anteed bandwidth though the bandwidth distributed to a certain ONU must be less than its maximum bandwidth. When this limitation generates surplus undistributed bandwidth, it is distributed recursively.

(B) Delay control

It is possible to choose one of two classes, low-delay or normal delay, as required. The low-delay class can be used for delay-sensitive services such as VoIP (voice over Internet protocol) or video communication. The low-delay class can achieve high TCP (transmission control protocol) throughput because it can send TCP ACK (response acknowledgment) messages back with low delay.

The mechanism of the DBA function is explained below (see **Fig. 6**).

(1) Each ONU sends a bandwidth-request message, which indicates the amount of upstream data stored in the ONU's transmission buffer.

(2) The DBA algorithm calculates the allowed transmission slot consisting of the transmission start time and transmission duration for each ONU. This calculation is done based on the amount of upstream data stored in ONU transmission buffers.

(3) Each ONU is notified of two allowed transmission slot calculated in step (2) by a transmission-allowed message. One is for sending the next bandwidth-request message and the other is for sending upstream data.

(4) In accordance with the allowed transmission slot notification, the ONU sends a bandwidth-request message and upstream data that had been stored in its buffer.

Steps (1), (3), and (4) conform to MPCP, which was standardized according to IEEE 802.3ah. The DBA algorithm that we developed operates using the MPCP framework; however, any DBA algorithms themselves, i.e., step (2), are outside the scope of standardization, so the DBA algorithm is a service-differentiating element.

4.2 ONU authentication

When the GE-PON system is used for a personal access service like B-FLET'S, there is a concern that the automatic discovery and registration function could allow access by unauthorized users. Therefore, an ONU authentication function has been included to make it impossible for unauthorized ONUs to communicate with the service network via the OLT (**Fig. 7**).

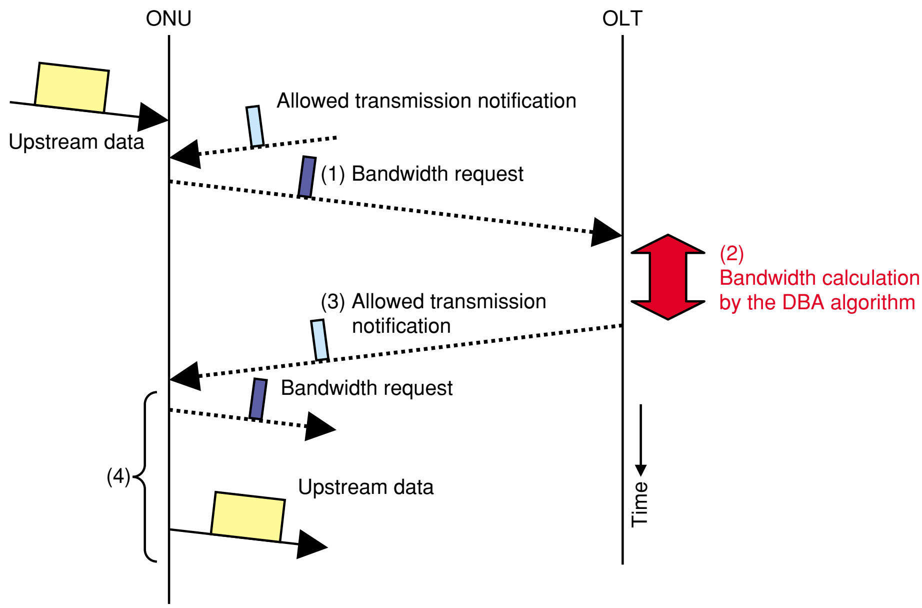


Fig. 6. Mechanism that enables DBA.

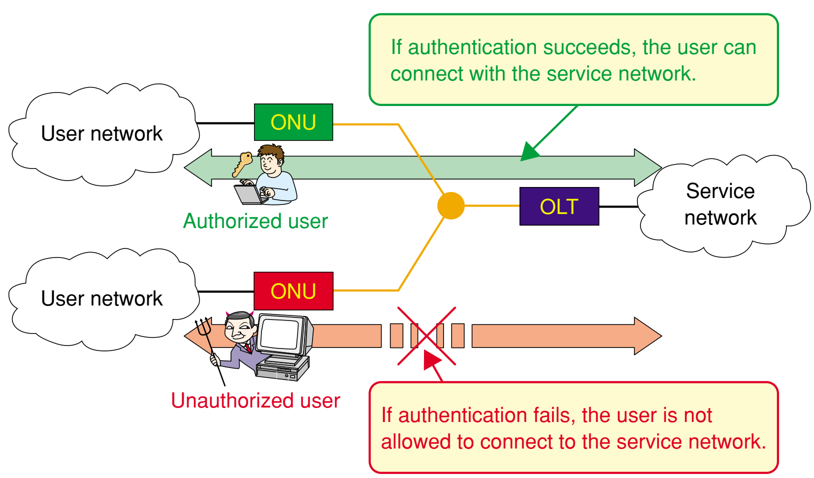


Fig. 7. Connection to the service network through authentication.

4.3 Encryption

PON downstream transmission is a broadcast, so a frame destined for a certain ONU also reaches other ONUs. To prevent unintended ONUs from eavesdropping on and analyzing the frames destined for another ONU, the system uses encryption with a different encryption key for each LLID.

4.4 Priority control

In the ONU, multiple queuing, classified according to IEEE 802.1D/Q priority, is performed for both the upstream and downstream directions, and high-priority frames are transferred first. This makes it possible to support delay-sensitive applications such as VoIP.

4.5 System OAM

IEEE 802.3ah specifies operation, administration, and maintenance (OAM) only for GE-PON data links. OAM for the whole commercial system is out of its scope. Therefore, we defined system OAM functions and managed objects that satisfy our carrier-grade operating demands.

5. Assuring interoperability

Although the various specifications discussed above give the GE-PON system flexibility and enable system differentiation in term of features, they may lead to interoperability problems among multiple systems. In particular, functions implemented in hardware like the encryption function will require a common specification, otherwise GE-PON will turn into a custom-made service operator's system like ones in the past, and further cost reductions and service extensions will be limited. To ensure that the GE-PON system can be widely procured, multi-vendor interoperability between the OLT and ONU is essential. Our system achieves interoperability among the products of different system vendors.

6. Future plans

We plan to work on adopting standardized technologies such as IEEE 802.1AE/af, which specifies encryption and authentication mechanisms, to promote interoperability and the incorporation of ONUs into consumer products. As a result, we hope that users will be able to buy ONUs in ordinary electrical appliance stores and install them themselves. We also plan to improve maintainability by considering feedback about current services.

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Koji Ochiai

Chief, FLET'S Service Division, Broadband Service Department, Consumer Business Headquarters, NTT East Corporation.

He received the B.E. and M.E. degrees in applied physics from the University of Tsukuba, Tsukuba, Ibaraki in 1995 and 1997, respectively. In 1997, he joined NTT Access Network Service Systems Laboratories, Chiba, Japan and engaged in R&D of access systems, providing both narrowband TDM services and broadband access services, such as the STM-PON system series and the basic rate interface over synchronized symmetric digital subscriber line (BRI over SSDSL) system and also engaged in R&D of the GE-PON system. Since April 2005, he has been engaged in upgrading the operations of the B-FLET'S service series in his present post.

Tsutomu Tatsuta

Senior Research Engineer, First Promotion Project, NTT Access Network Service Systems Laboratories.

He received the B.E. degree in electronic engineering from the University of Electro-Communications, Chofu, Tokyo in 1991. He joined NTT in 1991. In 1996, he moved to the Network Systems Development Department and worked on the development of the STM-PON system. Since 2001, he has been engaged in R&D of the GE-PON system. He contributed to the standardization of G.984.1 in ITU-T as an editor.

Takashi Tanaka

Senior Research Engineer, Head, Supervisor, First Promotion Project, NTT Access Network Service Systems Laboratories.

He received the B.E. degree in electrical engineering from Shibaura Institute of Technology, Tokyo in 1986. He joined NTT in 1986. From 1987, he was engaged in the development of transport system equipment. From 1999, he was engaged in the development of the FLET'S service series providing broadband Internet access. Since 2002, he has been engaged in joint development of optical access equipment in his present post.

Osamu Yoshihara

Chief, Ubiquitous Services Department, NTT Communications Corporation.

He received the B.E. and M.E. degrees in applied physics from the University of Tokyo, Tokyo in 1994 and 1996, respectively. In 1996, he joined NTT Technology and Development Support Center in Chiba, Japan, where he was engaged in the development of the STM-PON system. In 1997, he moved to NTT Access Network Service Systems Laboratories, Chiba. From 2001, he was engaged in R&D of the GE-PON system. Since April 2005, he has been engaged in development of access network services in his present post. He is a member of the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan.

Noriyuki Oota

Optical Access Innovation Project, NTT Access Network Service Systems Laboratories.

He received the B.E. and M.E. degrees in electrical and communication engineering from Tohoku University, Sendai, Miyagi in 1998 and 2000, respectively. In 2000, he joined NTT Access Network Service Systems Laboratories, Chiba, Japan. Since then, he has been engaged in research on a high-speed passive optical network and systems. He is a member of IEICE and IEEE.

Noriki Miki

Senior Research Engineer, Supervisor, Optical Access Innovation Project, NTT Access Network Service Systems Laboratories.

He received the B.E. and M.E. degrees in electronics engineering from Shinshu University, Nagano in 1982 and 1984, respectively. In 1984, he joined the Yokosuka Electrical Communication Laboratory, Nippon Telegraph and Telephone Public Corporation (now NTT), Kanagawa, Japan, where he was engaged in R&D of digital subscriber loop transmission systems. Since 1991, he has worked on R&D of fiber-optic access systems. In 1999, he received the IEICE Achievement Award. He is a member of IEICE and IEEE.