NTT R&D Forum 2005 Workshop Lectures

The special feature in this issue presents five workshop lectures given at NTT R&D Forum 2005 held at Yokosuka R&D Center on Feb. 24 and 25. They followed the keynote lectures "Actions to Achieve a New Broadband Society" by Norio Wada, President and CEO, NTT, and "R&D to Create the Resonant Communication Environment" by Yuji Inoue, Senior Vice President and Executive Director of Department III, NTT. The workshop lectures review the trend and state of the art of NTT's most important technologies, describe NTT's R&D efforts, and predict their future development. They were originally given in Japanese.

Lectures were:

- Access Network Technology for Diverse Services
  by Takamasa Imai, NTT Access Network Service Systems Laboratories
- Optical Core Networks
  by Kazuo Hagimoto, NTT Network Innovation Laboratories
- Secure Technology
  by Tomoo Fukazawa, NTT Information Sharing Platform Laboratories
- Home Network & Networked Appliance Technology
  by Hisashi Ibaraki, NTT Cyber Space Laboratories
- Digital Media
  by Hiroshi Fuju, NTT Cyber Space Laboratories

References

- N. Wada, "Actions to Achieve a New Broadband Society," NTT Technical Review, Vol. 3, No. 4, pp. 6-15, 2005.
- Y. Inoue, "R&D to Create the Resonant Communication Environment," NTT Technical Review, Vol. 3, No. 4, pp. 16-25, 2005.

Access Network Technology for Diverse Services

Takamasa Imai†

Abstract

This article introduces some access network technologies developed for various different services. These are recently developed technologies for Gigabit Ethernet passive optical network (GE-PON) systems, optical access system installation, and broadband wireless systems. Technologies for future systems are also described.

1. Trends in broadband services

Since the 1990s, the evolution of the information era has been described using a series of keywords such as *mobile*, *multimedia*, *Internet*, and *ubiquitous*. During this period, the demand for communications has grown remarkably as services have changed from circuit-switched services for fixed telephones to Internet services using broadband technologies such as xDSL (digital subscriber lines), FTTH (fiber to the home) and CATV (cable TV).

As we move closer to a ubiquitous network society, the dominant form of communication will change to object-to-object from the conventional human-to-object and human-to-human types. Therefore, the amount of Internet traffic will grow dramatically in the near future. According to the experts, there are several key issues to be considered to achieve broadband and ubiquitous services: 1) security, 2) technical development to achieve high-performance services, and 3) the provision of a suitable infrastructure to achieve reasonably priced services that are easy to install and use. Meanwhile, ordinary users also tend to list security, reasonable price, large capacity (high performance), and ease of use as important factors. Furthermore, there are clearly very large regional differences in the progress of FTTH deployment in Japan. FTTH access services are significantly used in the suburbs of Tokyo and Osaka. However, they are still not popular in other regions. For example, when the percentage of homes with FTTH access was 3.5% in Tokyo, that in Aomori prefecture was only 0.2%. Accordingly, we need to consider these key issues in developing optical access technologies. It is also essential to conduct research and development to redress this regional imbalance.

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

2. Current state of access network technology

Now NTT plans to deploy a resonant network, which consists of a service/network control platform, core transmission networks, and access and user networks. For the access networks, a combination of optical and wireless access techniques are promising. For the successful introduction of broadband communication, we must reduce the cost of the access systems to a reasonable level and ensure that the systems have high performance and are easy to install and use. Here, I review some of the main technologies that have already been implemented for practical access systems in response to user demands.

2.1 Optical access systems

Optical fiber transmission systems have a large impact on telecommunication networks owing to the remarkable advantages of optical fiber cables such as low loss and broad bandwidth, which enable long-distance and large-capacity communication. However, the final connections between an optical network and a home have still relied on metal wire transmission until recently. Recently developed optical access systems employing passive optical network (PON) technology provide end users with optical fiber communication. In a PON, the time division multiple access (TDMA) technique enables transmission between equipment in the central office and a large number of users' devices. Moreover, most optical fiber cables can be shared among users. The first PON system was introduced in 1997. The most recent system delivers a transmission rate of 1 Gbit/s via an Ethernet interface, which is widely used for data transmission in homes (**Fig. 1**). The main technology employed in the system, Gigabit Ethernet PON (GE-PON), includes the key basic technologies of encryption and burst mode optical reception and the high-performance technologies of bandwidth and delay control.

(1) Encryption

PON downstream transmission is a broadcast, so a frame destined for a certain optical network unit (ONU) in a user's home also reaches other ONUs. To prevent other ONUs from eavesdropping and analyzing the frames not destined for them, encryption is performed and a different encryption key is used for each ONU.

(2) Burst-mode optical reception

For upstream transmission, the system is designed to avoid collisions among the signals from the large number of ONUs. The central office equipment is designed to receive burst signals whose power level varies according to the distance between the optical line terminal (OLT) and ONU (**Fig. 2**).

(3) Bandwidth control

Most users do not need a fixed large bandwidth all the time. They sometimes want a large bandwidth but normally need only a smaller bandwidth at other times. To match these needs, NTT has developed a system that guarantees a minimum bandwidth for each user, while additional bandwidth is delivered on a best-effort basis. This makes it possible to implement an economical system that can provide a large bandwidth when other users do not need so much.

(4) Delay control

NTT has developed a system that can be used for delay-sensitive services such as VoIP (voice over Internet protocol) or video communication. The system can choose one of two delay classes, either low-delay class for high transmission priority or normal-delay class for normal transmission priority, according to the delay requirement. Audio and video signals of the low-delay class are reliably transmitted almost immediately, while other (normal-delay class) signals are transmitted during free intervals. This makes it possible to provide a reliable yet economical service

- The pursuit of efficiency and evolution of high speed
- Combination with Ethernet technology (GE-PON)

	STM-PON	Broadband-PON (B-PON)	GE-PON (1000BASE-PX)
Standards	NTT proprietary specification	ITU-T G.983.1-4	IEEE 802.3ah
Transmission rate	16 Mbit/s	622 Mbit/s downstream 156 Mbit/s upstream	1 Gbit/s
Upstream/downstream multiplexing method	Time compression multiplexing (TCM)	Wavelength division multiplexing (WDM)	
Data transmission frame	STM	ATM	Ethernet
Year of commercial launch	1997	1999 (leased line) 2002 (FTTH)	2004

STM: synchronous transfer mode
ATM: asynchronous transfer mode

Fig. 1. Fiber-to-the-home (FTTH) systems (PONs).

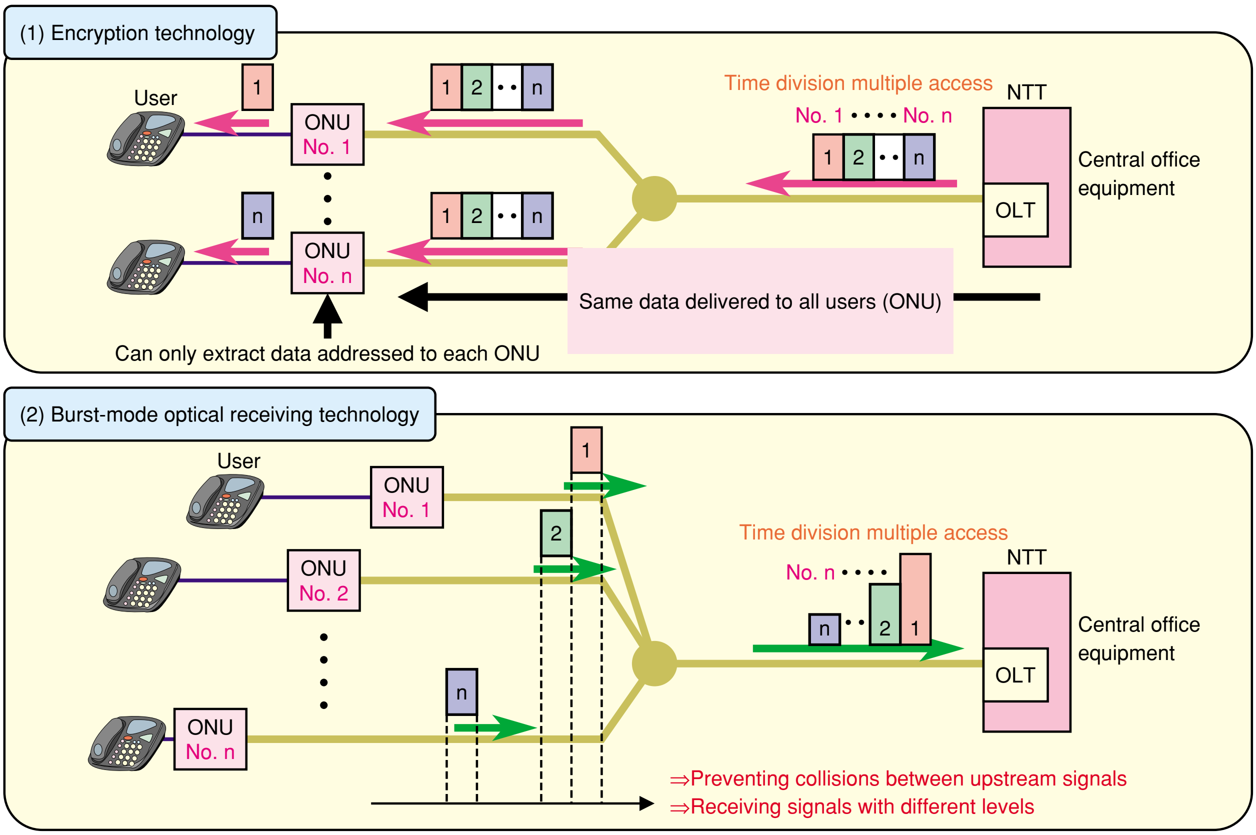


Fig. 2. Encryption/burst-mode optical receiving technology.

(**Fig. 3**).

In a GE-PON system, signals of different wavelengths are used in the upstream and downstream directions, allowing them to be transmitted in the same optical fiber by wavelength division multiplexing (WDM). Specifically, the upstream signals are transmitted at around 1.3 µm, the downstream signals are transmitted at around 1.5 µm, and a separate band for transmitting video signals is provided at 1.55 µm. The characteristics of this GE-PON system can be summarized as follows:

- It is capable of large-capacity transmission at a rate of 1 Gbit/s. It also incorporates techniques such as bandwidth and delay control that achieve a balance between high bandwidth efficiency and low delay.
- The use of standard Ethernet components reduces the system cost because no conversion of the Ethernet frames is required for local user networks.
- The sharing of center office equipment and subscribers' optical fibers also reduces the system cost.

2.2 Technology for optical access system construction

We have also developed optical wiring technology, which reduces costs to a reasonable level and makes FTTH services to be installed and used easily, to meet the demands of both quick and inexpensive construction.

(1) Indoor optical fiber cable

To facilitate network construction, we have developed a bend-insensitive optical drop/indoor cable. This cable can tolerate being bent to a radius of just 15 mm, which allows it to be installed much more neatly and makes it much easier to work with than conventional cable, which has a minimum bending radius of 30 mm.

(2) Extendable optical cord (flexible optical fiber curl cord)

We have designed optical fiber cords with a coiled section similar to the coiled cords used for telephone handsets. This optical fiber curl cord is as easy to use as a metal cable and can, of course, be connected to existing standard fibers.

(3) Cable sheath connector and optical connector cabinet/rosette

The conventional cabinets used to connect between exterior cables and indoor cables employ a mechanical splicing technique whereby the two cables are

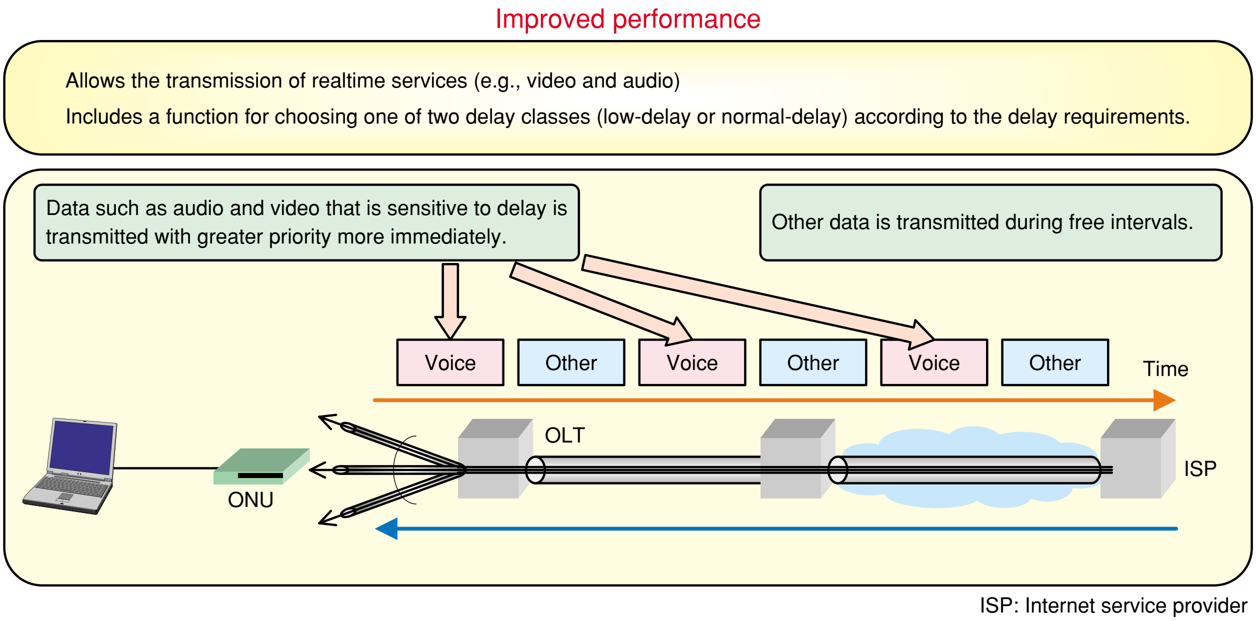


Fig. 3. Delay control function.

stripped down to the bare fiber and clamped together, which requires the use of sophisticated assembly techniques. On the other hand, our newly developed cabinet uses optical connectors (cable sheath connectors) that can be attached directly to the cable. This method does not require us to remove the optical fiber cable jacket, so we have no need to store spare lengths of fiber in the cabinet. Thus, it can improve construction efficiency. In combination with the abovementioned bend-insensitive optical cable, this method enabled us to reduce the volume of the optical cabinet by 65%.

(4) Non-conducting optical fiber drop-cable

The ends of optical fibers are supported by tension members. Conventionally, these tension members have been made out of metal and have thus had to be earthed to prevent damage from lightning strikes and the like. By making these members out of fiber-reinforced plastic (FRP) instead, we have managed to eliminate the need for earthing, thereby making cables much easier to install. As a result, we have been able to reduce the time to install optical fiber cables by about 20%.

2.3 Wireless access

For areas where it is difficult to retro-fit optical fiber networks into existing structures such as apartment blocks, we have developed a fixed wireless access (FWA) system. We made an economical high-speed (46-Mbit/s) access system by providing wireless hubs on telegraph poles and installing an antenna in each home to communicate with a hub. This system is also useful in areas where there is a demand for broadband access service but the demand is not yet sufficient for economical installation of an optical fiber system, for example, in new towns in rural areas.

3. Prospects of access network technology

With a medium-term target of 30 million customers for optical fiber access, we are setting our sights on the arrival of an era when optical communication is taken for granted. In this respect, it is essential not only to improve the cost performance but also to develop technologies that enable greater ease of use for both subscribers and installation engineers. Some technologies aimed at achieving this goal are described below.

3.1 Optical access systems

In current optical access systems, a PON architecture based on the time division multiple access (TDMA) scheme improves the cost performance. But the wide bandwidth of optical fibers should make it possible to achieve more economical systems for services with even wider bandwidth. Wavelength division multiple access (WDMA) is one promising technology for systems with a wide effective bandwidth. Furthermore, code division multiple access (CDMA) is a promising candidate as a future technology.

(1) Wavelength division multiple access

To ensure a good return on investment (ROI) in network infrastructure deployment, it is very important to suppress the initial investment and judge subsequent investment flexibly according to the actual demand trend. Wavelength division multiplexing (WDM) technology has good potential as a cost-effective investment. For example, by assigning a wavelength to a service menu, we can simultaneously provide various services with different protocols and bit-rates on only one transmission cable. To provide additional services, we do not need to install additional optical transmission cables or reconstruct the whole transmission system, but only need to prepare a low-cost optical component (WDM filter). Moreover, by assigning a wavelength to each user on a system with shared transmission cables (i.e., a PON system), we can independently provide and upgrade the transmission bandwidth of each user (**Fig. 4**).

However, conventional WDM equipment (especially WDM transceivers) is so expensive that it is difficult to utilize WDM technology widely in access network systems. Conventional WDM equipment consists of the optical transceiver and electrical signal processing parts, which are mounted in the same package. As a result, whenever a service upgrade is required, we must replace the whole package, even when we only need to change the WDM transceiver module. To make matters worse, a spare package must be kept for each type of wavelength, transmission distance, and user interface, which leads to the manufacturing of a wide variety products in small quantities and makes inventory control difficult. These factors make the conventional WDM system expensive.

To overcome these problems, we have recently developed a "pluggable WDM system" in which the optical transceiver part is separated from the electrical signal processing part. This makes service upgrading and inventory control of a WDM system much simpler. Instead of keeping various types of spare packages, we only need to keep pluggable optical transceivers. By replacing just the pluggable optical transceiver instead of the whole package, we can upgrade various services flexibly and quickly according as user requirements. Moreover, this pluggable design will strongly contribute to the standardization of optical transceivers, which have been the most expensive component of a WDM system, and lead to a drastic reduction in the cost of optical transceivers.

In addition, we can easily join an installed transmission system to a pluggable WDM system by plugging a pluggable WDM transceiver directly into already-installed transmission equipment and assign-

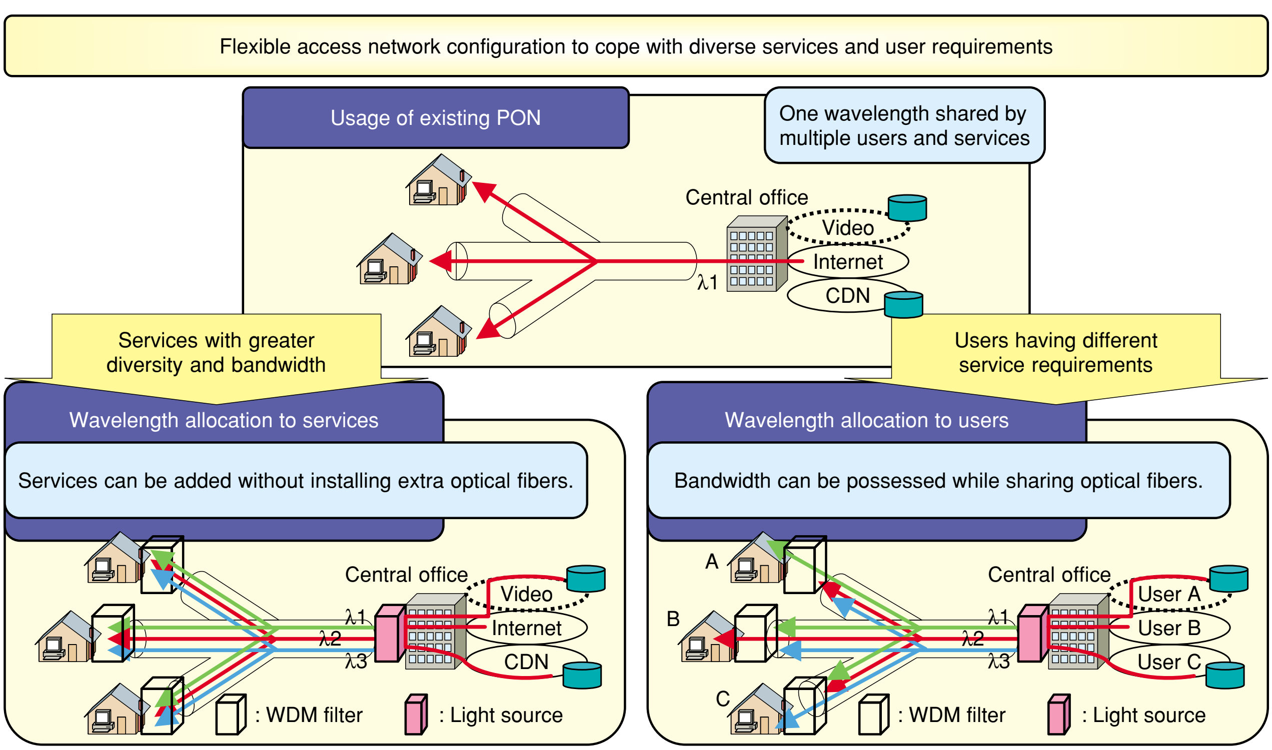


Fig. 4. Application of WDM technology to access networks.

ing another wavelength to this equipment. In this way, we can effectively utilize previously installed equipment without additional investment in transmission equipment and cables.

Recently, we have proposed a fully pluggable WDM system including multiplexing/demultiplexing functions using a pluggable WDM filter that can directly connect to a pluggable transceiver module. By combining these pluggable optical modules as easily as stacking toy blocks, we can flexibly meet users' requirements not only for various services, but also for various network topologies (such as point-to-point, point-to-multipoint, and cascade configurations).

Thus, the pluggable WDM system, which is attractive for cost-effectiveness and flexibility, should lead to WDM technology being applied to the access network.

(2) Optical code division multiple access (CDMA)

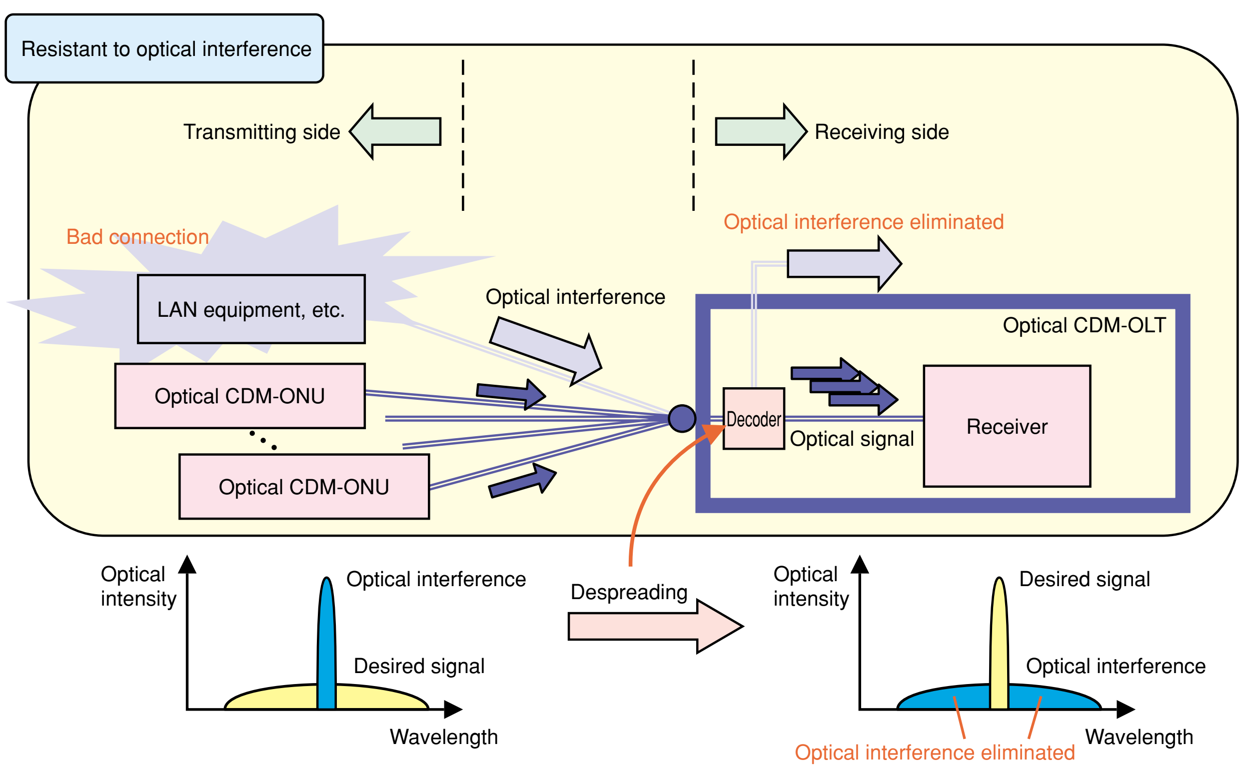
Code division multiplexing (CDM) is a popular multiple access technique used in cellular phone systems. It has many advantages compared with other multiplexing techniques. We are investigating the possibility of applying this technique to future optical networks.

The characteristics of optical CDMA include a significant reduction in optical interference and improved spectral efficiency. When a user connects incorrectly, the signal is normally obscured by the interference light and impossible to receive. But in a CDMA system, most of the optical interference can be eliminated by the despreading function and the signal be received correctly (**Fig. 5**).

This technique can also be exploited to allow upstream and downstream signals to be transmitted simultaneously at the same wavelength. Furthermore, CDMA makes it easy to reduce the signal crosstalk between adjacent wavelengths and has the potential to improve the spectral efficiency compared with WDM schemes.

3.2 Optical access system construction

Various transmission characteristics can be achieved by providing holes around the fiber core. A "hole-assisted" bend-insensitive optical fiber is less sensitive to bending, so no bending loss occurs even when the bend radius is very small. This technique can substantially reduce an optical fiber's bending loss while making it easier to install and easier to han-



LAN: local area network

Fig. 5. Some advantages of optical CDMA technology.

dle. Such an optical fiber cord can withstand being tied in a knot, bent at right angles, or even folded back on itself, making it useful not only in situations where the cable must be laid down neatly, but also in ones where there is little space available for the installation and accommodation of optical equipment. We are investigating hole-assisted bend-insensitive optical fiber cord for future use in optical access system construction.

3.3 Wireless access

For wireless access technology, the main issues for future study are to provide high-quality wideband services on a par with optical transmission speeds (over 100 Mbit/s), expand service areas, simplify indoor wiring, and reduce equipment and installation costs more.

4. Conclusion

The main research and development issues for access network technology are large capacity (better performance), cost reduction to a reasonable level, and ease of use. We increased network capacity by developing GE-PON (optical fiber) links via ADSL (asymmetric digital subscriber line). In the future, we will exploit the wideband properties of optical fibers in order to provide a more comfortable communication environment and quality suitable for the ubiquitous era. We have already achieved costs similar to those of metal connections at the user end, and we will go on to develop extremely cost-effective broadband services by exploiting WDM and CDM. We have already developed a number of facilitating techniques for optical access network construction.

As future research, we plan to develop more user-friendly systems by simplifying the wiring process, developing pluggable WDM technology that can be connected with ease, and adapting to whatever circumstances arrive by continuing our efforts in other areas such as wireless networks.

Profile

■ Career highlights

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

He received the B.E., M.E., and Dr. Eng. degrees in electronics engineering from Osaka University, Osaka, Japan, in 1980, 1982, and 1992, respectively. In 1982, he joined the Electrical Communication Laboratories of Nippon Telegraph and Telephone Public Corporation (now NTT), where he has been engaged in R&D of optical fiber transmission systems including long-distance and access systems. He served as a vice-chair of the Paper Committee of SubOptic 2001 in Kyoto. He is a member of IEEE, the Institute of Electronics, Information and Communication Engineers (IEICE) of Japan, and the Japan Society of Applied Physics. He received the Young Engineer Award from IEICE in 1990 and an IEICE Communication Society Activity Testimonial in 2000.