Optical Access Technology for High-speed Broadband Services

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Recently, fiber-to-the-home (FTTH) to support high-speed broadband services has been spreading widely and the number of FTTH contracts has passed 20 million in Japan. There are high expectations that optical access networks will become even faster and handle larger amounts of data so that they can be used for services that deliver high-resolution images, for peer-to-peer (P2P) services, and as a way to remove load for mobile services that are becoming increasingly faster. It is also hoped that these networks will serve as infrastructure to help cope with the improving quality of various services and help provide new cloud services. We have been providing a mass production-based GE-PON product supporting this popular FTTH and developed the 10G-EPON system, which applied ASICs of the main PON processing functions, and also an equipment power-saving mechanism based on the IEEE standard. Through this technological development, we are going to cope with demands for high-speed and large-capacity FTTH access networks. This paper describes the trends of standardization and technological development in next-generation optical access networks, and presents our approach to future work from the viewpoint of these trends and based on system development.

1. Introduction

Broadband access by general users in Japan is now in the period of popularization. **Figure 1** shows changes in the number of subscriptions to broadband services based on statistics provided by the Ministry of Internal Affairs and Communications.[1)]

The number of subscriptions to broadband services as of the end of December 2012 was 53.59 million, of which the number of subscriptions to fiber-to-the-home (FTTH) services was 23.55 million, showing an increase, and the number of subscriptions to digital subscriber line (DSL) services has continued to decrease to 5.74 million. The number of FTTH subscriptions accounts for 43.9% of the subscriptions to overall broadband services and the number of FTTH subscriptions is increasing in all prefectures in Japan. Significantly, the number of subscriptions to 3.9G mobile phone packet communication services and to broadband wireless access (BWA) services has increased to 13.63 million and 4.66 million, respectively, which indicates that mobile and broadband wireless access is explosively expanding.

This increase in access to broadband services requires an optical access platform to be put in place and extended in order to support future subscription increases and service enhancement of FTTH and to accommodate the expansion of the wireless access traffic.

One pillar to support an optical access network is Gigabit Ethernet Passive Optical Network (GE-PON), which was standardized as IEEE[2)] 802.3ah in 2004 and is widely in use in the FTTH field. Up to now, Fujitsu has shipped more than 6 million GE-PON optical network units (ONUs) that are installed at the customers' premises.

This paper presents the system development of and Fujitsu's approach to an even higher-speed, wider-band optical access platform. This platform is based on the mass production technology for GE-PON devices and it is being developed in view of the trends of standardization and the latest technology, while taking into consideration wireless broadband access.

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2. Popularization and capacity enlargement of FTTH

PON technologies, which are at the core of an optical access platform, use an optical coupler mounted on a utility pole to divide an optical transmission path between an optical line terminal (OLT) at the telephone office and an ONU installed at the customer's premises. Sharing an OLT with multiple ONUs in this way allows fiber optics to be effectively used, thus making for an economical system. Along with the decrease in the device cost, it gives FTTH users a moderate sense of satisfaction with regards to the service fees, and hence helps to make FTTH more popular.

The services include so-called triple play or quadruple play services, which are integrated with video streaming, telephone, Internet and (in the case of quadruple play) wireless services. In addition to the connection service, there is also on-demand TV, online games, e-commerce and user-generated services provided as applications on the Internet. Furthermore, the so-called hybrid TV has improved the user experience by combining terrestrial digital TV and wired Internet.

These video-related services are in a trend toward high-definition images, leading to increased FTTH traffic.

Based on the experience of the Great East Japan Earthquake, message board services that make use of social networking services (SNSs), blogs and Websites in disaster situations and digital signage have been utilized and services linking the Web and TV/video have been advanced. Through these, ICT infrastructure is being built at an increasing speed and is beginning to become established in real life as remote consultation systems and/or resident administrative services, thereby strengthening information provision and disaster measures.

In addition, as offload or backhaul for wireless access at the core of ubiquitous access that is anticipated to increase further, or as infrastructure for various cloud services, machine-to-machine (M2M) communications and big data utilization, FTTH is expected to be in even wider use in the future; it will require support for large-volume traffic. For this reason, the GE-PON system as an optical access platform for FTTH must have an

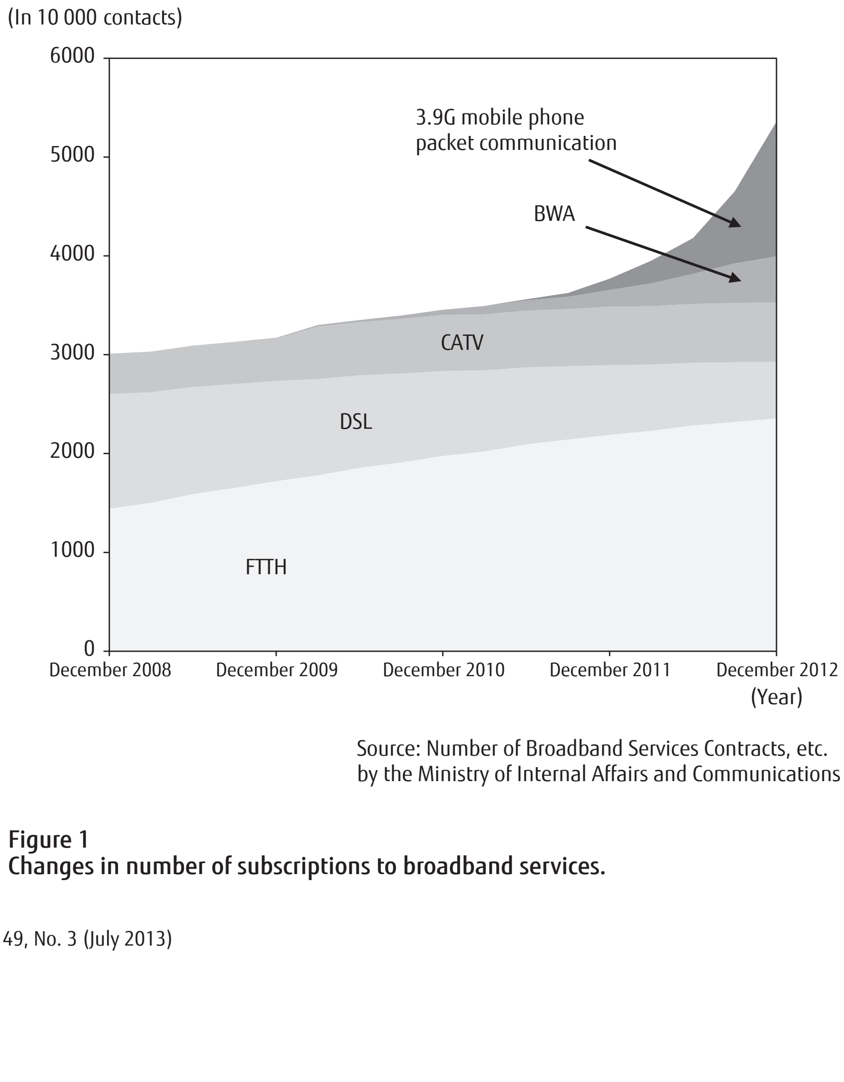

Figure 1
Changes in number of subscriptions to broadband services.

increased capacity, be upgraded and undergo changes to accommodate emerging new services.

In order to provide these services, it is also necessary to have support for various service classes (service grade), and have devices that can operate at a lower latency and over a wider band, and make social contributions such as saving power. The enhancement of FTTH for the purpose of realizing these functions also requires increased system capacity, downsizing and/or integration of devices and ensured security suitable for the entrance of home networks as well as the pursuit of economic efficiency. Furthermore, wireless traffic will need to be offloaded via femtocells or Wi-Fi/WiMAX not only in homes but also at wireless access points in various places. It is expected to be utilized as a service mix in combination with various network services including healthcare ones. FTTH will need to develop and become an infrastructure that fills these needs.

As described above, FTTH as the foundation of the next-generation core/metro networks needs to be even more stress-free for users. In addition, as offload for wireless traffic like smartphone services that is expanding at an explosive rate FTTH must meet the need for a better user experience. In this way, FTTH is facing unavoidable and urgent issues such as support for continuously increasing traffic and various service classes.

3. Trends of standardization

Standardization of optical access PONs has been completed by IEEE with 802.3ah (GE-PON: 1.25 Gb/s downstream and upstream) and by ITU-T[3] with the G.984 series (G-PON: 2.5 Gb/s downstream; 1.25 Gb/s upstream). This standardization is in view of building infrastructure for and operation of gigabit-level commercial services. Standardization has also been completed for 10 gigabit-level access with both IEEE and ITU-T. With IEEE, standardization of 802.3av (10G-EPON: 10 Gb/s downstream; 10 Gb/s upstream [symmetric-rate] or 1 Gb/s [asymmetric-rate]) was completed in September 2009. With ITU-T, the G.987 series (XG-PON: 10 Gb/s downstream; 2.5 Gb/s upstream) was approved as a recommendation in June 2010. At present, they are in their maintenance mode.

As shown in **Figure 2**, these standards are intended to help enterprises carry out mass production and reduce their costs by allowing major materials such

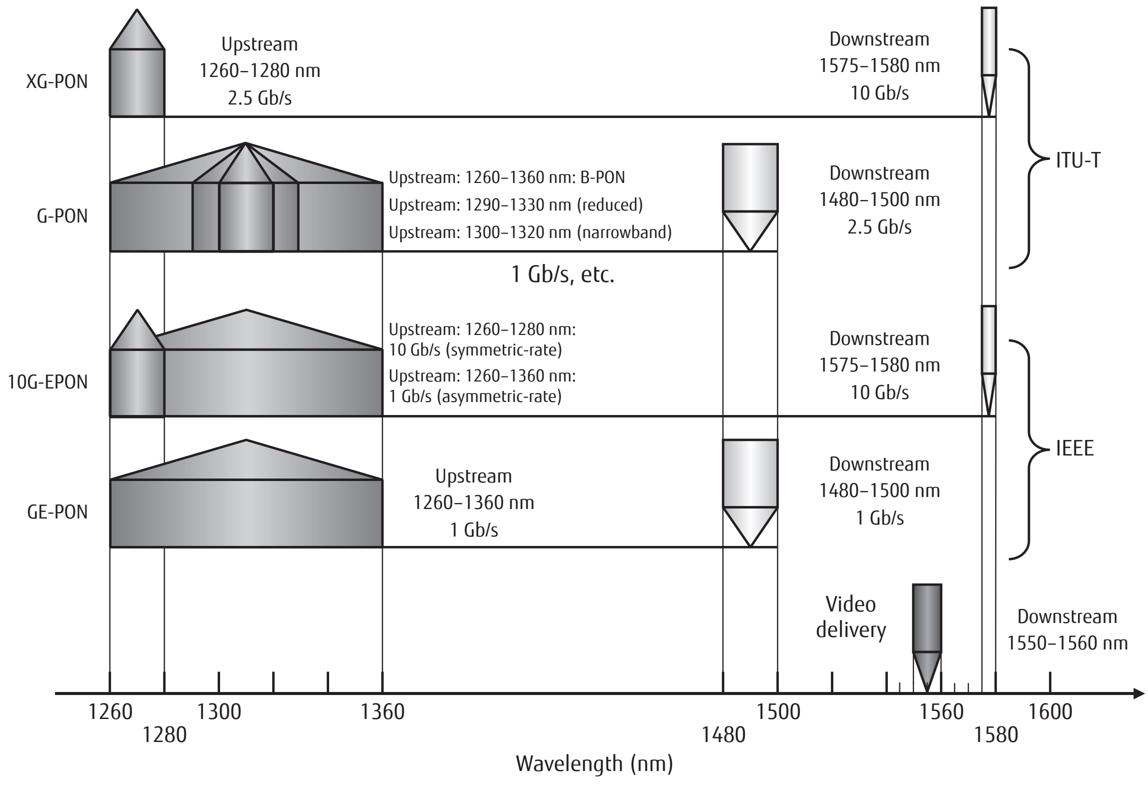

Figure 2
Wavelength allocation by PON standardization.

as optical device systems to be commonly used in both standards in terms of transmission speed and wavelength allocation.

For PON standardization, compatibility testing and interoperability studies for up to the 10 Gb/s level are currently conducted from the physical and data link layers to systems. With ITU-T, interoperability tests are being conducted by multiple XG-PON vendors in cooperation with the Broadband Forum (BBF)[4]. With IEEE, P1904.1 Service Interoperability in Ethernet Passive Optical Networks (SIEPON)[5] has been established for ensuring interoperability. The technical specifications are mostly completed and scheduled for standardization in June 2013. In step with this, compatibility test standardization is scheduled for completion in December 2013. Fujitsu is actively contributing to the standardization by making written contributions and through other means.

As a measure against global warming due to CO_2 emissions, which is a global environment issue, power conservation of communication devices is positively reflected in the standardization specifications, which makes standardization a means of social contribution.

IEEE defines power-saving Ethernet as Energy-Efficient Ethernet (EEE) with 802.3az. The above-mentioned P1904.1 SIEPON also defines sleep control mode for PON interfaces. A mechanism is included that stops the optical transmitter and/or receiver of an ONU when there is no user traffic in order to save power.

ITU-T also defines optical transmitter/receiver sleep control mode for G-PON interfaces as Recommendation G.Sup45 (March 2009) and, in a similar manner, a power-saving mechanism is also included in the standardization specifications for 10G-PON interfaces of G.987.3 (XG-PON).

This shows an aspect of cooperative efforts by IEEE and ITU-T for standardization of communication devices.

One example of cooperation is that G.epon, which is being discussed by ITU-T, is intended for incorporating specifications related to operation, administration and maintenance (OAM) of IEEE P1904.1 SIEPON in the framework of G.988, which is a general-purpose ONU management and control interface (OMCI) in ITU-T Recommendation.

On the whole, standardization of optical access PONs requires further discussion on the details of multi-vendor interoperability but is basically completed up to the 10 gigabit level.

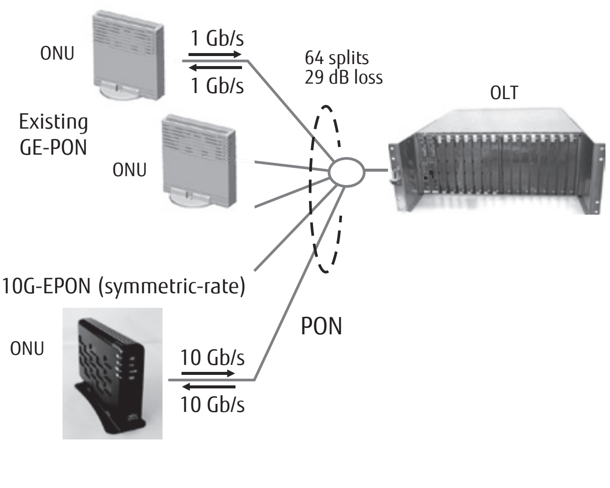

Figure 3
Example of 10G-EPON system configuration.

4. 10G-EPON system development

Based on the external situation and the state of standardization described above, it is considered to be a matter of time before there is an increase in the speed and capacity of GE-PON. For 10 Gb/s level PON systems, which have already been standardized by both IEEE and ITU-T, technological development is now in a transition, going from the operation checking phase for optical transceiver and PON processing media access control (MAC) functions to the equipment development phase. Fujitsu's 10G-EPON system development is also in the equipment development phase for commercialization.

An example of system configuration that uses the developed devices is shown in **Figure 3**. To an optical distribution network enabled by optical power splitter of PON, a GE-PON ONU compliant with the existing IEEE 802.3ah and a 10G-EPON ONU compliant with IEEE 802.3av can be connected in coexistence with each other. A PON interface of the 10G-EPON OLT compliant with IEEE 802.3av performs optical transmission of 10 Gb/s and 1 Gb/s downstream signals by wavelength-division multiplexing (WDM) and optical reception of 10 Gb/s and 1 Gb/s upstream signals by time division multiple access (TDMA). A 10G-EPON ONU performs optical reception of 10 Gb/s downstream signals and burst optical transmission of 10 Gb/s upstream signals with the time and length specified by the OLT. As the optical loss budget between the OLT and the ONUs, 29 dB is supported.

The major equipment specifications are shown in **Table 1 (a)** for OLT and **Table 1 (b)** for ONU. The appearances of OLT and ONU are shown in **Figure 4 (a)** and **Figure 4 (b)** respectively.

The following lists the major characteristics of the developed system.

1) 10 Gb/s signals of PON interface compliant with standardization specifications of IEEE 802.3av
2) 1 Gb/s signals of PON interface compliant with standardization specifications of IEEE 802.3ah
3) Co-existence of GE-PON and 10G-EPON ONUs accommodated
4) 64 splits supported for PON section
5) Reduced device size for 10G-EPON ONU comparable to existing GE-PON ONU
6) PON processing chip in the form of ASIC integrated in both 10G-EPON OLT and ONUs
7) Advanced 40 nm CMOS process technology adopted for 6) above in order to curb any increase in power consumption
8) SIEPON Draft-based power saving function provided that uses linkage between OLT and ONUs
9) OLT/ONU optical modules provided that aim at reduced cost, mass productivity and low power consumption
10) Standard OAM and extended OAM supported by PON interface
11) As bridge functions, MAC learning function, VLAN function, DBA (dynamic bandwidth allocation) function and priority control function provided
12) Multicast function, encryption/decryption function, authentication function and maintenance/control function provided

Of these characteristics, mixed accommodation (coexistence) mentioned in 3) above can be additionally explained as follows. The downstream communication from the OLT to an ONU has a wavelength of 1575–1580 nm for 10 Gb/s and 1480–1500 nm for 1 Gb/s and the signals of the respective communications are transmitted by WDM. In an existing GE-ONU, 10 Gb/s signals are blocked by a wavelength filter and there is no influence. In a 10G-EPON ONU, 1 Gb/s signals are blocked by a wavelength filter and only 10 Gb/s signals are received. Meanwhile, 10 Gb/s and 1 Gb/s signals of the upstream communication are transmitted by TDMA, which allows the signals to be separated and differentiated by the receiver of the OLT. This TDMA control is linked with the DBA function of the OLT to prevent the 10 Gb/s signals and 1 Gb/s signals from colliding and provides a fair bandwidth allocation for the signals.

For the power saving function mentioned in 8), the sleep control mode of an ONU may be one of two types: stopping only the transmitter of the ONU optical module, or periodically stopping both the transmitter and receiver. In either mode, the operation enters sleep mode when there is no traffic to the ONU for the purpose of saving power. This can be implemented together with Ethernet interface power-saving low power idle (LPI) in the user-network interface (UNI) standardized by IEEE.

For the bridge functions in 11), there are various parameters for ensuring service quality, and they are used in view of the traffic type and service class.

In this way, the developed 10G-EPON system aims not only at giving support for speed and capacity increases but also at power conservation and cost reduction by having technological progress of devices and ASICs. It is also intended to allow network operators to reduce their capital expenditure (CAPEX) by letting them make effective use of the existing assets, especially allowing them to inherit the optical distribution network (ODN) that involves public works for social infrastructure and the realization and inheritance of video streaming service overlay.

5. Future technology trends

PON technologies are becoming capable of supporting commercialization at the 10 Gb/s level compliant with standardization through the 10G-EPON system development. Sales of existing GE-PON systems have expanded to extend the broadband access environment and, by making effective use of the existing assets, the next high-speed, wide-band PON technology has been launched. Before commercial services can be provided, there is still the hurdle of achieving reasonable prices for general users, which is characteristic of access systems, but application to business use is now within reach.

As a PON technology to support an even wider band, more branching and longer distance, transmission speeds of 40 Gb/s and 100 Gb/s are also being discussed. This is aimed at the next-generation PON in

Table 1
10G-EPON equipment specifications.

(a) OLT

Interface	PON interface	10GBASE-PR30 IEEE 802.3av-compliant (optical loss: 29 dB supported) * IEEE802.3ah-compliant for 1 Gb/s
		No. of ONU connections (multi-split): 64 or more
		Co-existing connection of 1 G/10G-EPON ONUs
		Standard OAM, extended OAM supported
	SNI interface	10 G Ethernet
Functional specifications	Encryption/decryption function	IEEE 802.1AE-compliant
	Authentication function	Provided
	Bridge function	MAC learning function
		VLAN function
		DBA function (dynamic bandwidth allocation)
		Priority control function
	Multicast function	Provided
	Power saving function	IEEE P1904.1 SIEPON sleep control mode supported
	Data management function	Provided
	Maintenance/control function	Various alarm processing and monitoring/control functions

(b) ONU

Interface	PON interface	10GBASE-PR30 IEEE 802.3av-compliant (optical loss: 29 dB supported)
		Standard OAM, extended OAM supported
	UNI interface	1 G/10 G Ethernet
Functional specifications	Encryption/decryption function	IEEE 802.1AE-compliant
	Authentication function	Provided
	Bridge function	MAC learning function
		VLAN function
		Priority control function
	Multicast function	Provided
	Power saving function	IEEE P1904.1 SIEPON sleep control mode supported
		IEEE 802.3az power saving function
	Maintenance/control function	Various alarm processing and monitoring/control functions

Size: 480 (W) × 553 (D) × 173 (H) (mm)

(a) 10G-EPON OLT

Size: 75 (W) × 241 (D) × 151 (H) (mm)

(b) 10G-EPON ONU

Figure 4
10G-EPON system equipment.

view of accommodating an increase of bandwidth-consuming or rich content service traffic and mobile traffic, pursuit of economic efficiency from the perspective of users by multi-split, and longer distance and improved economic efficiency by station integration.

The Full Service Access Network (FSAN),[6] a consortium for optical access, calls this technology NG-PON2 and positions it as the next PON technology beyond 10 Gb/s. ITU-T also acts in concert with this and has started discussing the approval of the next-generation optical access system as a recommendation.

Required specifications[7] as a network operator include support for transmission speeds of 40 Gb/s downstream and 10 Gb/s upstream as the aggregate capacity per feeder and at least 1 Gb/s for the ONU UNI, a fiber length between the OLT and an ONU of 40 km with a distance variation of within 40 km and at least 64 splits.

As a method of realizing this next-generation optical access system NG-PON2, application of multiplexing schemes including ultra-high-speed TDM technology, WDM technology, orthogonal frequency division multiplexing (OFDM) technology, coherent technology and hybrids of these technologies are under consideration.

With the timeline for building infrastructure assumed to be around 2015, TWDM-PON (PON that applies TDM-WDM hybrid technology) is adopted as the first solution. Considering that standardization of the existing TDM-PON for up to the 10 Gb/s level has been completed, this can be said to be a realistic solution capable of realizing the 40 Gb/s level by a four-wave multiplex WDM scheme. WDM (including wavelength tunability) overlay may be permitted and coherent reception or OFDM scheme may be applied as required, and this continues to be under consideration. R&D not restricted by any time frame is expected to continue in the future.

As an ultra-high-speed TDM technology, bit-interleaved PON of 40 Gb/s downstream is being discussed as a method of reducing power consumption, and it has also been taken up by the GreenTouch Consortium[8] as a measure for improving energy efficiency.

WDM-PON offers excellent security with a user or service assigned its own wavelength. There are various forms of implementation including externally seeded WDM-PON, wavelength reuse WDM-PON, tunable WDM-PON, ultra-high-density WDM-PON and self-seeded WDM-PON and multi-channeling of optical modules, cost reduction and power consumption reduction will continue to be discussed. Business applications as a mobile backhaul are also under consideration.

There is also an OFDM-PON scheme, in which CMOS electrical signal processing technologies such as DAC/ADC and digital signal processing (DSP) used for core/metro systems are applied to access systems for capacity increase by high-frequency utilization efficiency. This is intended to allow the bandwidth to be effectively used by assigning a sub-carrier to each ONU or sharing it between multiple ONUs.

Coherent PON is first applied to core networks along with the progress of digital signal processing and device technologies. Based on its practicality, the advantages as an access system PON including high sensitivity characteristics and wavelength selectivity are put to best use.

Important points in these future technologies include taking an approach to migration paths and how to make use of the assets invested in the improvement of the existing broadband environment. From the perspective of ODN, in particular, coexistence as in the present system development is preferable in which the ODN is not fundamentally changed from the existing PON system and is gradually migrated to a new system.

A greenfield area where no fiber has been installed yet allows replacement, in which both the existing OLT and ONUs are replaced without any constraints from the existing ODN requirements. In addition, it is possible to install ODN transformation, in which the existing power splitter-based optical split is converted into, or added to by, a new wavelength filter-based split for overlay.

Judging from the state of FTTH diffusion in Japan, however, the implementation of ODN transformation in the choice of technology to be applied to the next-generation access systems is expected to be gradual and take time with the areas of application focused on and the existing effective assets taken into account.

It is inseparable from the building of the next-generation core/metro networks and service and technology trends must be taken into consideration.

6. Conclusion

This paper has first described the state of broadband communication in Japan with the focus on the popularization of FTTH and Fujitsu's GE-PON products that support its development.

It has also mentioned that future FTTH requires a capacity increase to accommodate services involving high-definition images and wireless access traffic offload or backhaul and that standardization of optical access PON for up to the 10 Gb/s level has been completed. In light of this, IEEE standard-based 10G-EPON system development has been conducted and PON technology established to be ready for commercialization, and this has also been described in this paper.

Fujitsu intends to realize FTTH that supports a traffic increase, allows for power conservation and pursues economic efficiency while keeping an eye on the trends of development and standardization of the next-generation access PON technologies. This will enable us to offer a platform that can be made use of by each user as an infrastructure for access system FTTH.

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