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Evolving Network Technologies

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Evolving Network Technologies

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Technical Reports

Overview

Author: *Takashi Nishimura**

Contribution to the Special Issue on Evolving Network Technologies

As faster mobile services, in addition to fixed-line broadband, become available, smartphones and tablet devices are spreading rapidly and network traffic is growing. Therefore, telecommunications carriers urgently need to prepare a high-speed, large-capacity network in an economical way.

In response, a next-generation optical-access 10G-EPON system is being developed with a transmission capacity of 10 Gbps, which is 10 times larger than the 1-Gbps G-EPON system. Metro and core networks are also expected to increase their transmission capability up to 10 Tbps, which will be realized by emerging new technologies such as a digitally coherent and sophisticated signal processing scheme.

Meanwhile, practical applications of home information and communication technology services are attracting attention, where imaging devices, sensors, cameras, and other sophisticated customer premise equipment are linked with the network to add value.

Mitsubishi Electric has been offering highly reliable and economical network systems by pioneering the development of devices, transmission systems, and other component technologies. This special issue presents the state of Mitsubishi's development of the abovementioned technologies for optical access, metro, and home networks.

Group Vice President, Communication Systems Group and General Manager, Communication Networks Center

40 Gbps/100 Gbps Large-Capacity Optical Transmission Equipment

Authors: *Shinobu Nomatsu**, *Mamiko Shibuya** and *Kazuyuki Ishida***

1. Introduction

In order to meet the rapidly increasing demand for communications over metro networks and international submarine cable networks, it is essential to secure larger transmission capacity and higher equipment reliability. Indispensable technologies to satisfy these requirements include: design and verification technologies that realize large-capacity transmission of 40 and 100 Gbps per wavelength, high-density packaging technology to implement such large-capacity transmission capability, high-reliability monitoring technology for large-capacity networks, and optical protection technology to minimize service downtime. This paper introduces two types of wavelength division multiplexing (WDM) optical communications equipment for submarine cable and metro network applications, both of which were developed by applying the large-capacity and high-reliability technologies.

2. Technologies for Larger Capacity and Higher Reliability

2.1 High-density packaging technology

As the devices used in optical communications equipment have become more integrated, the heat generating source has become more localized. To solve this problem, the structural thermal design has been optimized. The heat pipe shown in Fig. 1 dissipates the heat from digital-analog mixed LSI that realizes a new modulation scheme. Combined with the optimized heat source layout, the heat dissipation effect has been improved by 25% from the conventional level. These technologies are also applied to the 40 and 100 Gbps transponders, which are commonly used in both types of WDM optical communications equipment for submarine cable and metro network applications. The 40 Gbps muxponder and transponder cards are now mountable in a high-density installation rack for conventional 10Gbps optical transmission system. They can double the transmission capacity in the same chassis size; and the 100 Gbps transponders can triple the transmission capacity. As an application example, Fig. 2 shows the optical transmission rack with high-density packages of WDM optical communications equipment for submarine cable networks, along with its main specifications.

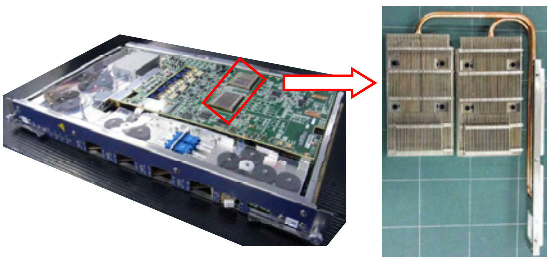

Fig. 1 Heat pipe mounted on the transponder

Item	Specification
Power supply voltage	DC 48 V
Operating temperature range	5–40°C
Number of wavelengths accommodated	Up to 15 waves @ 40 G muxponders/rack Up to 9 waves @ 40 G transponders/rack
Chassis size	2,200(H) × 600(W) × 400(D) (mm)

Fig. 2 High-density packaging optical transmission rack and main specifications

2.2 Design and verification technologies for large-capacity transmission

To enhance the transmission capacity by increasing the bit rate and number of multiplexed wavelengths while maintaining the transmission distance of the conventional 10 Gbps optical communications system, evaluation equipment for ultra long-haul transmission was developed to verify the 40 and 100 Gbps transmission characteristics. Figure 3 shows a spectrum waveform of 40 Gbps waveform signals after simulated transmission over 9,000 km. The evaluation equipment can simulate various conditions in actual service environments, such as different types of optical fibers, signal wavelength bands and transmission distance, thus allowing us to perform high-precision evaluation of the transmission characteristics at the design stage.

2.3 High-reliability monitoring technology for large-capacity networks

As the network capacity increases, the element management system (EMS) requires even higher reli-

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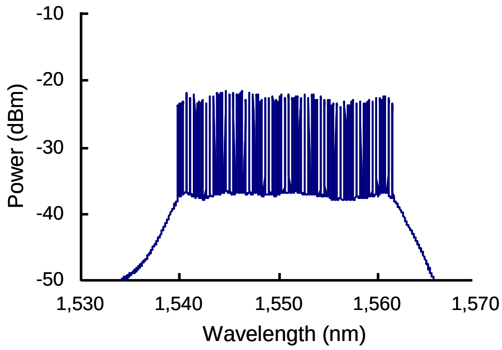

Fig. 3 Ultra long-haul transmission evaluation equipment (upper) and wavelength multiplexed spectrum after transmission over 9,000 km (lower)

ability. To ensure that the monitoring function continues even if the EMS is damaged by earthquake, fire and other natural causes, the servers must be remotely located in a redundant configuration. Hot-standby redundancy generally requires frequent server-to-server synchronization, and thus a transmission band must be secured between the servers. The servers hold information for managing the transmission equipment conditions as well as the users and server's own conditions. The information for managing the transmission equipment conditions includes the setting data and failure status of each component, failure history, and transmission quality; and thus the data volume is large. To achieve remote placement, the amount of synchronization data has successfully been reduced by setting the currently used and standby servers to communicate independently with the transmission equipment, and restricting server-to-server communication to the server's own information. These improvements make it possible to implement hot-standby redundancy even where a sufficient transmission band cannot be secured between the servers. Remotely located EMS servers in the redundant configuration are already in service for submarine cable and metro network applications.

3. WDM Optical Communications Equipment for Submarine Cable Applications

The system design for the submarine cable system must provide high reliability and flexibility, because it handles international and large-capacity data transmission traffic at various transmission rates. To meet this requirement, we have developed a 40 Gbps multi-service muxponder, which can accommodate both 10 and 40 Gbps together and provide long-haul transmission. In addition, we have developed an optical protection technology to provide a highly reliable service.

3.1 40 Gbps multi-service muxponder

The external appearance and main specifications of the 40 Gbps multi-service muxponder are shown in Fig. 4 and Table 1, respectively.

Fig. 4 External appearance of 40 Gbps multi-service muxponder

Table 1 Main specifications of 40 Gbps multi-service muxponder

Item	Specification
Line side interface	
Transmission rate	OTU3v (50 Gbps)
FEC	Ultra FEC (High performance forward error correcting code)
Client side interface	
Compatible interface	STM-64, 10GbE, OTU2
Others	
Power supply voltage	DC −48 V
Operating temperature range	5 – 40°C
Number of wavelengths accommodated	Up to 9 waves @ 40 G TPND/rack (3 units/rack)

The optical signal-to-noise ratio (OSNR) of the 40 Gbps optical signal needs to be 6 dB higher than that of the 10 Gbps signal. It is also sensitive to the nonlinear optical effect in the optical fiber. The 40 Gbps muxponder has achieved long-haul transmission by adopting a new modulation/demodulation technology and a high-performance forward error correction. The upgrade to 40 Gbps is advantageous not only for securing larger capacity but also for lower power consumption and a smaller footprint of the land terminal equipment.

The 40 Gbps muxponder can accommodate up to four channels of a mixed combination of STM-64, 10GbE, and OTU2 services having different signal speeds. The hardware design allows flexible change of clock rate and data bus, and thus OTU2e, OTU1e and other interfaces can also be accommodated by upgrading the software.

3.2 High-reliability optical protection equipment

The optical protection technology, which protects the traffic on the submarine cable network by switching to the standby system regardless of its data type, is also required to deal with diversified interfaces. Corresponding to the mixture of various client interfaces with the 40 Gbps muxponder, new optical protection equipment has been developed. Its external appearance and main specifications are shown in Fig. 5 and Table 2, respectively.

Fig. 5 External appearance of optical protection equipment

Table 2 Main specifications of optical protection equipment

Item	Specification
Maximum number of protected wavelengths	Up to 64 wavelengths
Switching time	100 ms or less (Fast Mode) 11–20 s or less (Slow Mode)
Switching mode	Fast / Slow / Disabled Mode
Switching command	- Lockout of Protection (LP) - Forced Switch (FS) - Manual Switch (MS)
Automatic switch back	Available
Priority control	High priority service is selectable

The N:1 optical protection scheme has been adopted, where one standby wavelength is provided for N wavelengths transmitted over the submarine cable. The N:1 switching is performed using an optical switch based on the automatic protection switching (APS) protocol provided by the OTN overhead, which is an extension of the International Telecommunication Union – Telecommunication Standardization Sector (ITU-T) G.845 standards. Quad multiplexed 10 Gbps client signals are simultaneously switched within 100 ms.

To accomplish the simultaneous switching within 100 ms, the appropriate signal transfer method and detection time were selected and optimized in accordance with the response speed of each block of the transponder and switch. In addition, for extension to the 40 Gbps transponder, an OTU3 interface can be provided by extending the APS protocol using the OTU3 overhead area.

4. WDM Optical Communications Equipment for Metro Network Applications

In response to the increasing metro network capacity, we have developed WDM optical equipment that can transmit 40 Gbps × 40 wavelengths, by applying high-density packaging, low-power consumption, and heat dissipation design technologies. In addition, to allow for further capacity increase in the future, this equipment is designed to accommodate 100 Gbps transponders that achieve 100 Gbps transmission per wavelength.

4.1 Low-power consumption 40 Gbps muxponder

A new transponder with a line rate of 40 Gbps/wavelength has been developed using the same common functional blocks (optical amplifier and optical add/drop multiplexer) designed for the 10 Gbps transmission equipment. As the line rate is increased to 40 Gbps/wavelength, a higher robustness against OSNR and optical spectrum narrowing is generally required. These challenges were successfully overcome by applying Mitsubishi Electric's proprietary modulation and demodulation technology.[1] The external appearance and main specifications of the applied 40 Gbps muxponder are shown in Fig. 6 and Table 3, respectively.

Fig. 6 External appearance of 40 Gbps muxponder for metro network applications

Table 3 Main specifications of 40 Gbps muxponder

Item	Specification
Line side interface	
Transmission rate	OTU3v (44 Gbps)
Modulation method	Pre-equalization DQPSK
FEC	Ultra FEC (High performance forward error correcting code)
Client side interface	
Compatible interface	STM-64, 10GbE-LAN/ WAN × 4 Ch (mixed combination can be accommodated)
Others	
Power supply voltage	DC −48 V
Operating temperature range	5 – 40°C
Number of wavelengths accommodated	Up to 30 waves @ 40 G TPND/rack (3 units/rack)

This equipment allows mixed transmission together with 10 Gbps signals, and thus upgrade can be performed without affecting existing services in operation. In addition, the footprint is reduced by 50% and the power consumption is reduced by up to 50% from the conventional level.

4.2 100 Gbps transponder

We have adopted digital coherent technology and newly developed error correction technology to realize long-haul transmission at 100 Gbps, which has been highly desired to meet increasing traffic demand and to utilize recently introduced 100 Gbps routers. In the digital coherent system, information is transmitted by using optical multi-phase modulation and two mutually orthogonal polarized waves, and the received signal is demodulated by digital signal processing. This system provides good spectral efficiency and transmission/reception performance, and thus is attracting attention as a promising technology for increasing transmission capacity. The combination of high-speed A/D converter and digital signal processing provides good compatibility with the soft-decision error correction technology. For application to this digital coherent system, a soft-decision low-density parity-check (LDPC) code has been developed. The triple-concatenated FEC codes, which combines this soft-decision LDPC code and two hard-decision codes, provide the error correcting performance as shown in Fig. 7.(2) A net coding gain of 10.8 dB (@1E-15) has been obtained, which is 4.6 dB better than that of the ITU-T G.975 standard Reed-Solomon (RS) codes. These technologies are applied to the 100 Gbps transponder for which the functional block diagram is shown in Fig. 8.

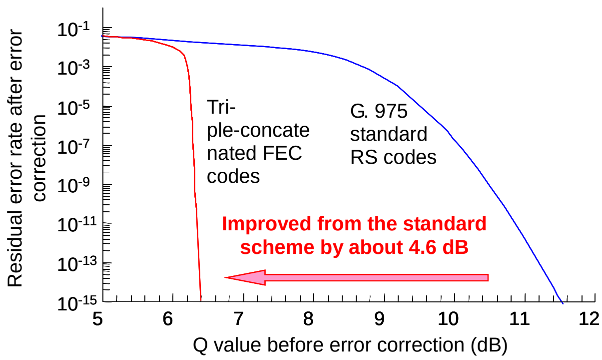

Fig. 7 Performance of triple-concatenated FEC codes

5. Conclusion

By applying the described large-capacity and high-reliability technologies, we have developed two types of WDM optical communications equipment for submarine cable and metro network applications. We hope that these pieces of equipment for 40 and 100 Gbps large-capacity optical communications will enhance the capacity and reliability of optical communications networks.

Part of this research and development work is the result of the following contract research projects of the Ministry of Internal Affairs and Communications: "Research on adaptive optical transport networks based on high-speed electronic signal processing technologies," "Research and development on ultra high-speed optical transmission system technologies (digital coherent optical transmission and reception technologies)," and "Research and development on ultra high-speed optical edge node technologies."

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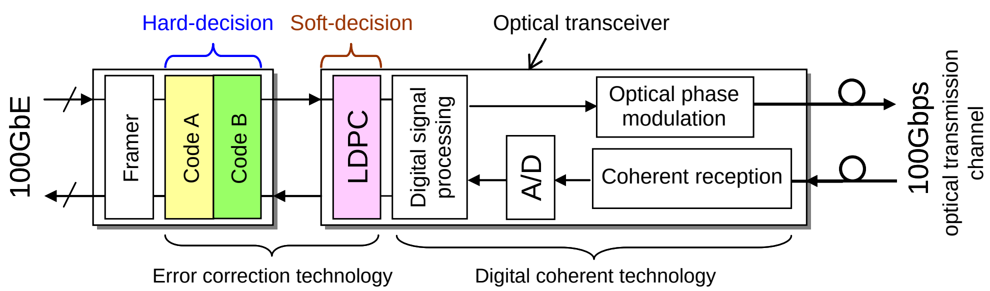

Fig. 8 Functional block diagram of 100 Gbps transponder

Development of EPON Systems for Global Market

Authors: *Kaneyuki Sakai** and *Ken Murakami**

1. Introduction

In the global market for broadband access lines, there is a high demand for wider bandwidth associated with the increase in video sharing and high-quality video delivery service, and for longer distance, multi-branching, and highly efficient accommodation in response to the rising number of subscribers.

This paper provides an overview of the equipment and features of the EPON systems (GE-PON system and 10G-EPON system) developed by Mitsubishi Electric for the global market. Chapter 2 presents the main specifications of the system; and Chapter 3 describes the key technologies applied to the system: large capacity, high reliability, high-speed backplane transmission, and power saving.

2. System Outline

2.1 System configuration

The chassis of the optical line terminal (OLT) is mountable on a 19-inch rack and is commonly used for both the GE-PON and 10G-EPON systems. The OLT can accommodate up to 16 PON line cards. The PON line cards, control cards and layer-2 switch cards can be configured in a redundant structure. The 10G-EPON system can accommodate mixed combinations of 1G-EPON and 10G-EPON line cards.

2.2 Main specifications

The main specifications are listed in Table 1.

Table 1 Main specifications of EPON system

Item	Specification
Equipment specification	
Unit size	19-inch rack mountable, 10U height
Slot configuration	PON line card : 16 slots Control card : 2 slots Layer 2 switch : 2 slots Expansion slot : 2 slots
Number of ports on each PON line card	(1) GE-PON system 8 PON ports/card (up to 128 PON ports/unit) (2) 10G-EPON system 4 PON ports/card (up to 64 PON ports/unit)
PON port speed (Installable ONU)	(1) GE-PON system Up 1 G/ Down 1 G (2) 10G-EPON system Each PON port can handle the following 3 modes: (a) Up 10 G/ Down 10 G (Symmetric) (b) Up 1 G/ Down 10 G (Asymmetric) (c) Up 1 G/ Down 1 G Different ONUs can be mixed on the same PON port.
Number of branches per PON port	(1) GE-PON system Up to 64 branches (2) 10G-EPON system Up to 128 branches
PON optical module	(1) GE-PON system PX20 + compliant XFP module (2) 10G-EPON system PR30/PRX30 compliant XFP module
Layer-2 switch capacity	480 Gbps
Functional specifications	
Redundancy control	(1) PON line card (PON protection function) (2) Control card (3) Layer-2 switch card (4) Power supply (5) EMS
Multicast function	IGMP/MLD transmission by single-copy broadcast (SCB)
Operation and maintenance function	(1) Triple churning encryption (2) ONU authentication (MAC address/Logic ID/Mix) (3) Alarm detection and notification (4) Performance monitoring and statistics alarm
Others	
Power supply voltage	DC −48 V
Operation temperature range	0°C – 40°C

3. Key Technologies

3.1 Large-capacity technology

In the GE-PON system, as shown in Table 1, each PON line card is equipped with eight PON ports. Figure 1 shows the external appearance of the OLTs of the EPON systems. Each PON port is equipped with a functional part for terminating the IEEE 802.3 compliant Multi-Point Control Protocol (MPCP).(1) The PON cards can be installed in 16 slots, and thus the GE-PON system can accommodate up to 128 PON ports.

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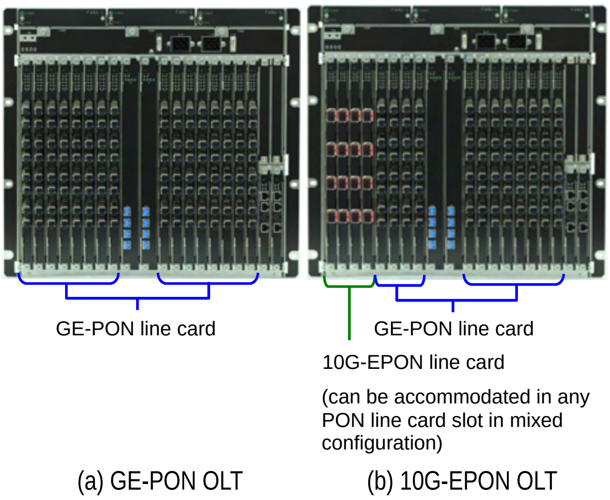

Fig. 1 External appearance of EPON OLTs

3.2 Redundancy Technology

As the capacity increases, so must the system reliability. To meet this requirement, the OLT and Element Management System (EMS) are configured, as illustrated in Fig. 2, in a redundant structure for each functional part in the EPON system.

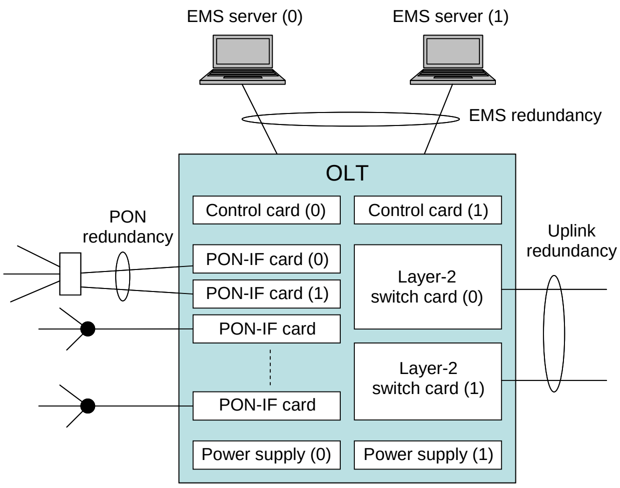

Fig. 2 Redundant structure

(1) The EMS servers provide a warm-standby 1+1 redundant system, which stays in waiting mode with the OS activated.

(2) The OLT achieves high reliability by implementing a redundant system for each functional part.

(a) The control cards provide a warm-standby 1+1 redundant system, and the power supply part is also redundant.

(b) The redundancy of the layer-2 switch card is based on the duplication of the cards; and redundancy of the uplink port is provided by various types of layer-2 protocols, such as link aggregation (LA) and spanning tree protocol (STP).

(c) As shown in Fig. 3, the system is provided with a PON protection function by means of redundancy for the PON line cards by duplicating the interface at the central office. Any failure of the interface at the central office gives a significant impact, and thus the optical root fibers are duplicated. This is not only in preparation for a failure, but is also applicable as a bypass route of optical fibers during construction work and/or upgrade of the PON interface.

3.3 Hi-speed backplane transmission technology

Each 10G-EPON line card in the OLT is equipped with four PON ports, which provide a total maximum traffic of 40 Gbps. The layer-2 switch card provides a switch capacity of 480 Gbps, with a 20 Gbps interface to the PON line card. Therefore, data transfer from the PON line card to the layer-2 switch card is oversubscribed to 20 Gbps (oversubscription ratio of 50%). To improve the subscriber accommodation efficiency, the backplane, i.e., card-to-card connection, must have sufficient transmission capacity. One of the challenges to achieving high-speed and large-capacity transmission on the backplane is the wiring of signals.

Utilizing the 10 Gbps backplane serial transmission technology based on the 10GBASE-KR interface, Mitsubishi Electric has developed a backplane that provides a transmission capacity of 100 Gbps per PON line

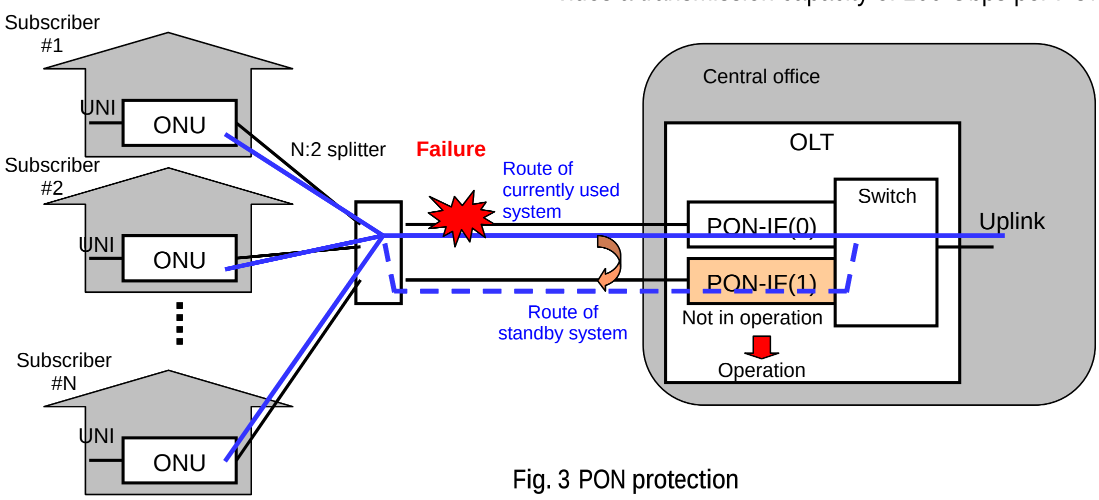

Fig. 3 PON protection

card (slot) and a maximum OLT capacity of 1.6 Tbps. Figure 4 provides a conceptual wiring diagram of this backplane.

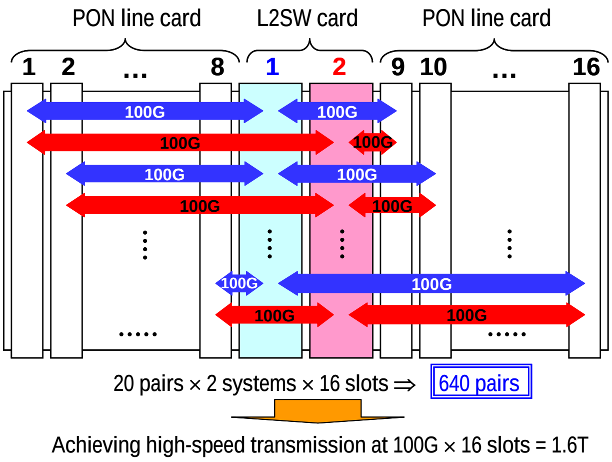

Fig. 4 Conceptual backplane wiring diagram

Regarding the trend in switch chips, commercially available chips already provide a switch capacity of several 100 Gpbs. By applying these chips to the oversubscription part of the PON line card, and fully utilizing the transmission capacity of 100 Gbps per line card (slot), for example as illustrated in Fig. 5, a PON line card equipped with 16 PON ports can achieve an oversubscription ratio of 62.5 % (160 Gbps → 100 Gbps).

In addition, on the backplane area for the layer-2 switch cards, which are oversubscribed from the 16 PON line cards, the wiring for 1.6 Tbps has already been implemented to provide upgradability for an even larger capacity through which several Tbps switch chips become available for application to the layer-2 switch card.

4. Power Saving Technology

In response to the recent ecology boom also occurring within the communications industry, many telecommunications carriers have introduced severe power saving criteria, especially for reducing the power consumption of ONUs.

In the GE-PON system for domestic use, Mitsubishi Electric has realized an ONU power-saving function compliant with IEEE P.1904.1 (Japanese standards: Package B).(2) IEEE P.1904.1 also specifies North American standards (Package A) and Chinese standards (Package C). The newly developed GE-PON system for the global market has cleared the power saving criterion of Package C; and plans are in place to implement this function in the 10G-EPON system.

The Package C type ONU power saving function is an OLT driven technology. The OLT monitors the occurrence of upstream frames from each ONU and downstream frames to each ONU; if no frame transmission or reception occurs to/from a certain ONU for a predetermined time, the OLT sends an instruction to the ONU to move to the power saving state; once the ONU receives this instruction, it moves to the power saving state. It is worth noting that the ONU keeps moving between the sleep state and wake state during one power saving period. The sleep time and wake time can be set by the EMS, and thus the network administrator is allowed to set these times considering the tradeoff between the frame delay time, or the recovery time from the power saving state, and the power saving efficiency.

When the OLT receives a downstream frame addressed to the ONU in the power saving state, the OLT sends an instruction to the ONU, during its wake period, to recover from the power saving state. Once the ONU receives this instruction, it recovers from the power saving state and notifies the OLT of its recovery. From the time that the OLT sends the instruction to recover from the power saving state until it receives the recovery message, the OLT accumulates downstream frames addressed to the ONU. If a large number of downstream frames are received during this period, a buffer overflow occurs in the OLT as illustrated in Fig. 6 (a), and high-priority frames such as voice and video frames risk being discarded. To minimize this risk, the OLT has a priority control function to reduce the possibility of discarding high-priority frames. Specifically, as illustrated in Fig. 6 (b), an individual buffer is provided for each priority level, and the accumulation buffer is determined based on the priority information of each downstream frame. Once the completion of recovery

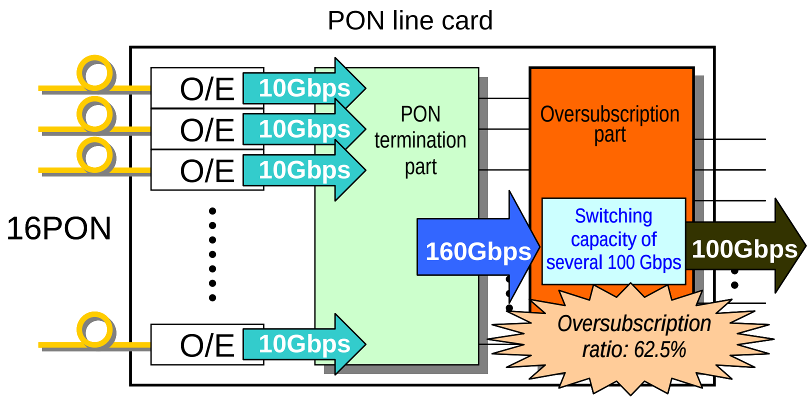

Fig. 5 Retaining and improving the oversubscription ratio for multiple ports

from the power saving state is notified, the OLT resumes frame transmission from a higher priority buffer. The class of service (CoS) value in the VLAN tag is used to determine priority information.

As illustrated in Fig. 7, the OLT achieves the power saving function while ensuring service quality through close coordination between the PON termination part, which monitors the frame occurrence from each ONU, and the oversubscription part, which performs priority control.

5. Conclusion

The newly developed EPON systems for the global market (GE-PON system and 10G-EPON system) have achieved multi-branching and wider bandwidth. In addition, the implementation and the equipment architecture employed in these systems were determined by looking into the future for a further increase in transmission capacity and reduction in power consumption. Mitsubishi Electric will continue to work on capacity enhancement, power reduction, and other performance improvements.

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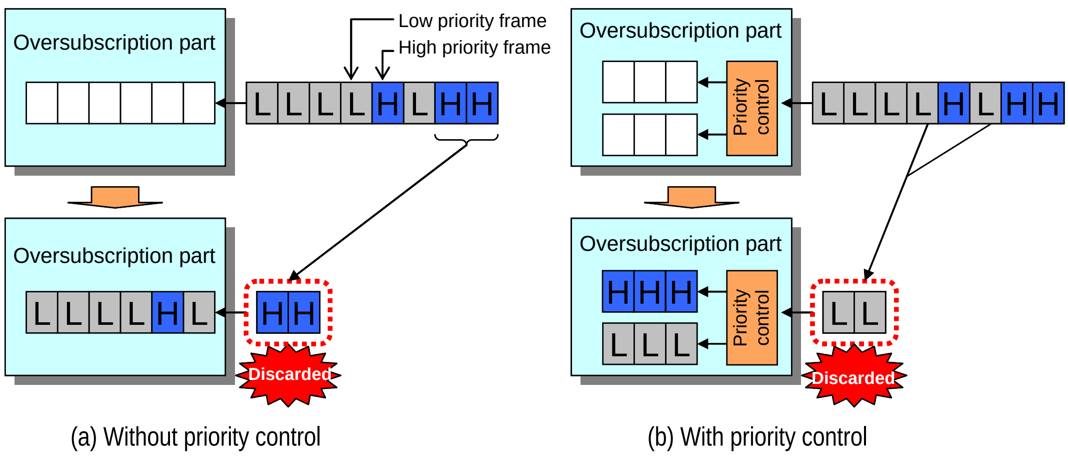

Fig. 6 Effect of priority control at the oversubscription part of the PON line card

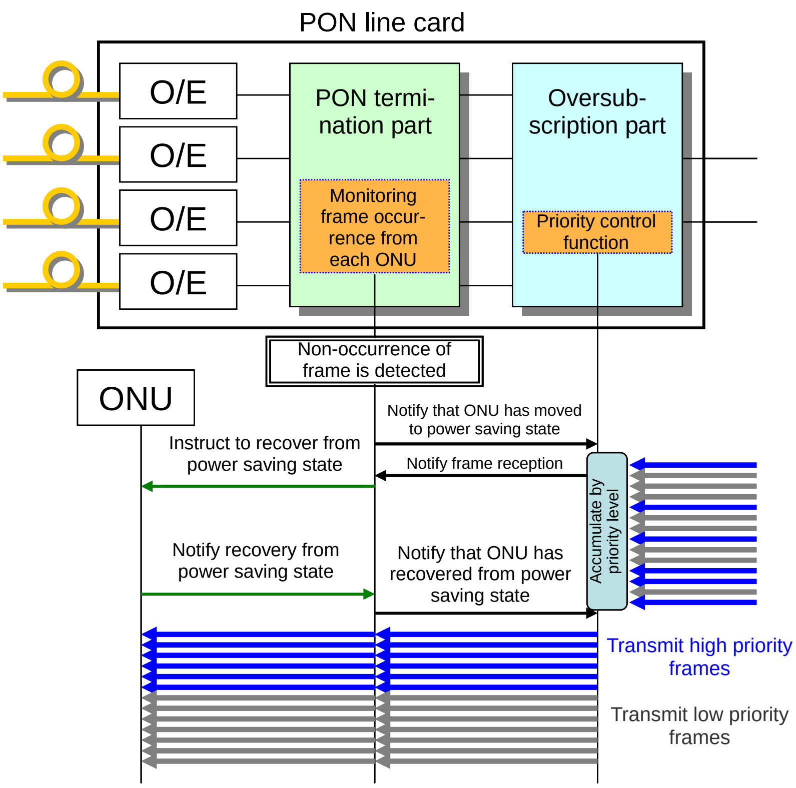

Fig. 7 Power saving by coordination between PON termination part and oversubscription part

Optical Transceiver for 10G-EPON

Authors: *Eitetsu Igawa** and *Satoshi Yoshima***

1. Introduction

As data traffic increases with further developments in the information-oriented society such as multi-channel high-definition video delivery and cloud communications service, fiber to the home (FTTH) services, among other broadband services, are widely spreading. Especially in Japan, the number of FTTH subscribers exceeded 21.4 million as of September 2011, accounting for 59.1% of all broadband subscribers. To cope with projected further increases in transmission traffic, the introduction of the 10G-EPON system is now highly expected. The 10G-EPON system provides 10 times higher transmission speed than GE-PON, which is the current mainstream of FTTH. This paper reports on the 10G-EPON dual-rate optical transceiver for optical line terminal (OLT) applications, and the optical transceiver for optical network unit (ONU) applications, as well as their core technology — dual-rate burst transmission technology.[1]

2. 10G-EPON System

An example system configuration for the 10G-EPON is illustrated in Fig. 1. To be compliant with the international standard IEEE 802.3av, the 10G-EPON system is assumed to coexist on the same fiber network (optical distribution network: ODN) with the existing GE-PON system; and thus, a 10G-ONU and a 1G-ONU must coexist in the same ODN. The optical wavelength band at 1.49 µm is used for the 1.25 Gbps downstream signal, whereas the 1.577 µm band is allocated for the 10.3 Gbps downstream signal; thus, these signals can be separated by the wavelength, and downstream signals at different bit rates are multiplexed by the wavelength division multiplexing (WDM) scheme. The broadcast scheme is used for both 10.3 and 1.25 Gbps downstream signals, and each ONU filters the optical wavelength band corresponding to its own transmission rate, and extracts the appropriate data only from the allocated time slot.

On the contrary, in the upstream direction, the optical wavelength band of 1.26–1.28 µm is allocated for 10.3 Gbps upstream signals and 1.26–1.36 µm for 1.25 Gbps, resulting in an overlapped range of 1.26–1.28 µm. Therefore, the time division multiplexing (TDM) scheme is used to avoid collision of optical signals by controlling the transmission timing of the 10.3 and 1.25 Gbps upstream packet signals.

Consequently, for the symmetric 10G-EPON system at a bit rate of 10.3 Gbps for both upstream and downstream signals, the ONU essentially needs the 10 G burst transmission technology to intermittently and quickly transmit 10 Gbps data, and the OLT requires the dual-rate burst-mode receiving technology to intermittently receive 10.3 and 1.25 Gbps packet signals, which are transmitted from various ONUs located at different distances and have different optical receiving power.[1, 2]

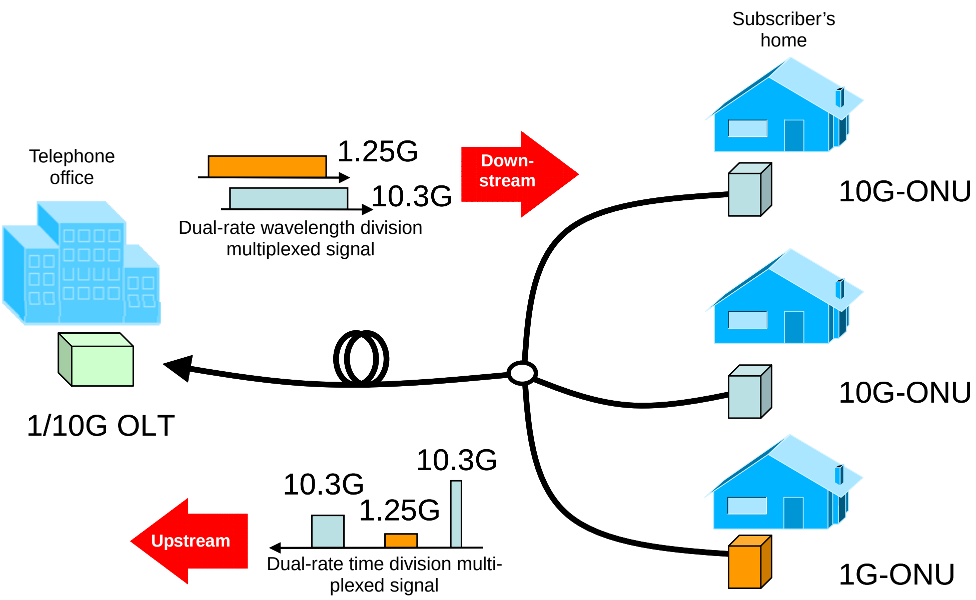

Fig. 1 Dual-rate 10G-EPON system

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3. Development of Optical Transceivers for 10G-EPON System

3.1 OLT optical transceiver

Figure 2 shows an outline configuration of the developed dual-rate OLT optical transceiver. The optical transceiver consists of a dual-rate burst-mode receiver, 1 and 10 Gbps transmitter parts, and a triplexer that integrates a distributed feedback laser diode (DFB-LD), an electro-absorption modulator integrated laser (EML), an avalanche photo diode (APD), and a preamplifier. The 1 and 10 Gbps transmitter parts are provided with driver ICs to drive the DFB-LD and EML, respectively, and are controlled by automatic power control (APC) circuits so that the desired optical transmission power and extinction ratio are obtained in the entire range of temperature and supply voltage. Meanwhile, the preamplifier integrated in the triplexer is provided with automatic gain control (AGC) and automatic threshold control (ATC) functions. AGC and ATC are used to adjust the gain and threshold level according to the received burst-mode optical signal to simultaneously accomplish both a wide dynamic range and a fast burst-mode response for both the 10.3 and 1.25 Gbps burst-mode receiving optical signals. The signal from this preamplifier is amplified by the limiting amplifier and converted to a dual-rate OLT optical transceiver output signal.

The dual-rate OLT optical transceiver is also provided with internal monitoring functions for the optical transmission power and LD drive current of both the 1 and 10 Gbps transmitters, and the optical receiving power of the dual-rate burst-mode receiver part. The monitored optical transceiver status can be notified to the OLT through the I2C (inter-integrated circuit) port.

Figure 3 shows the external appearance of the developed dual-rate optical transceiver, which is in the XFP package realized by optimizing its internal configuration and arrangement.

Figure 4 shows the burst-mode receiver output waveforms for 10 and 1 Gbps packets. This time, by implementing the AGC function that operates at a high speed only in the preamble part and at a slow speed in the payload part,(3) even if a 10 Gbps packet is received immediately after a 1 Gbps packet, or vice versa, each received waveform is regenerated within 240 ns, that is, high-speed burst-mode response characteristics are accomplished.

Table 1 shows the main characteristics of the developed OLT optical transceiver. Satisfactory performance, which satisfies the IEEE 802.3av PR30/PRX30 standards, is obtained in the entire range of temperature and supply voltage.

Table 1 Main characteristics of dual-rate OLT optical transceiver

10.3 Gbps	Characteristic
Transmission wavelength (μm)	1.575 – 1.580
Transmission power (dBm)	+2.0 – +5.0
Extinction ratio (dB)	> 9.0
Minimum receiver sensitivity (dBm)	< −28
1.25 Gbps	**Characteristic**
Transmission wavelength (μm)	1.480 – 1.500
Transmission power (dBm)	+2.0 – +7.0
Extinction ratio (dB)	> 6.0
Minimum receiver sensitivity (dBm)	< −29.7

3.2 ONU optical transceiver

Figure 5 shows the external appearance of the developed 10G-EPON optical transceiver in a SFP+ compliant case, which is realized by reducing the transceiver's overall power consumption and improving the heat dissipation by using an aluminum die-cast case.

Figure 6 shows the configuration of the developed transceiver. The optical transceiver consists of a transmitter circuit, a receiver circuit, and a bi-directional optical module (BiDi) that integrates a DFB-LD, an APD, a transimpedance amplifier (TIA), and a WDM filter. The

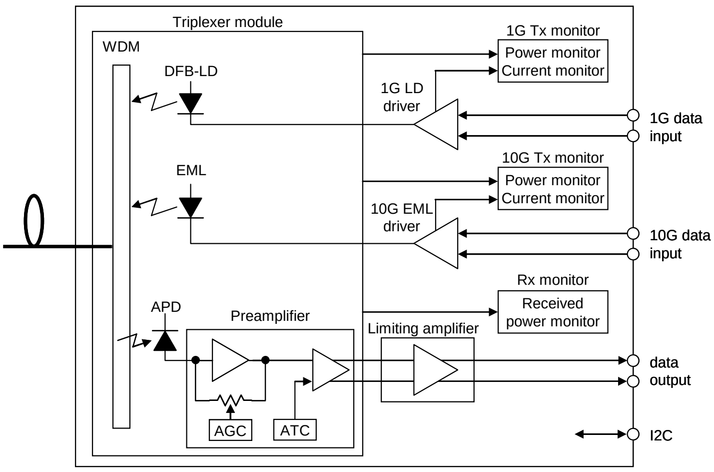

Fig. 2 Configuration of dual-rate OLT optical transceiver

Fig. 3 External appearance of dual-rate OLT optical transceiver

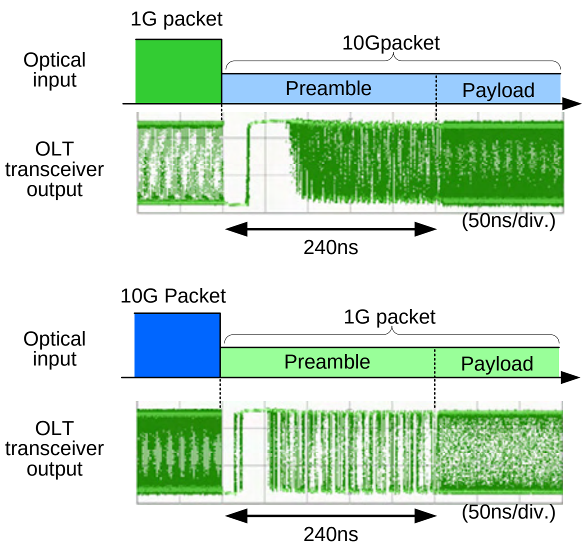

Fig. 4 Dual-rate burst-mode receiver output waveforms

Fig. 5 External appearance of ONU optical transceiver

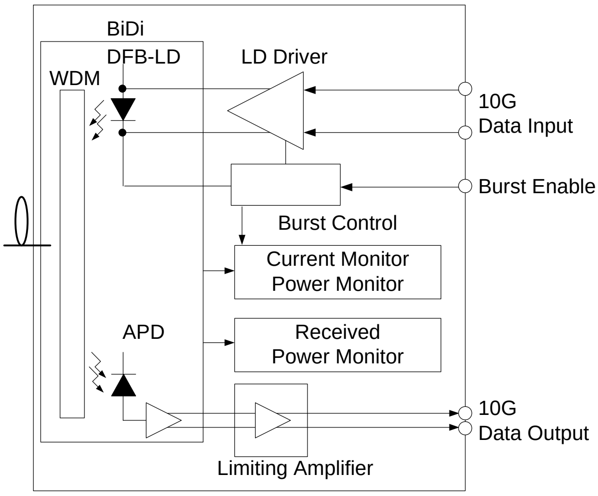

Fig. 6 Configuration of ONU optical transceiver

transmitter circuit is provided with an LD driver IC to drive the DFB-LD, as well as a burst-mode transmission

circuit to perform intermittent data transmission in response to transmission requests. In addition, an optical output monitor and other current detection circuits are provided to implement the monitoring function for notifying the ONU of operating conditions, such as the optical output power and reception power from the optical transceiver, and alarm occurrence. For enhanced compatibility, the interface and pin count are designed to be SFP+ compatible. By optimizing the number of control signals, burst-mode transmission performance has been ensured while reducing the number of control signals for the burst control circuit.

Table 2 shows the main characteristics of the developed transceiver. Satisfactory performance, fully compliant with the performance specified by the IEEE 802.3av PR30 standard, is obtained.

Table 2 Main characteristics of ONU optical transceiver

Item	Characteristic
Transmission wavelength (μm)	1.266 – 1273
Transmission power (dBm)	+4.0 – +9.0
Extinction ratio (dB)	> 6.0
Ton/Toff (ns)	< 512
Minimum receiver sensitivity (dBm)	< −28.5

4. Conclusion

An OLT optical transceiver in the XFP size and an ONU optional transceiver in the SFP+ size have been developed for the 10G-EPON systems. We have successfully implemented the core technology — dual-rate burst-mode receiver technology — in these devices, which will meet the market needs for compact size and compatibility.

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Architecture and Technologies for HGW

Authors: *Masahide Nishikawa** and *Shunsuke Nishio**

Home information and communication technology (ICT) service systems, where household appliances and devices are linked and interfaced with the home gateway (HGW) equipment, will soon be a reality.(1) This paper reports the architecture and relevant key technologies for HGW that we recently developed. This HGW enables flexible implementation of home ICT service application software, while retaining the robustness of lifeline services such as the telephone function.

1. HGW and home ICT

1.1 What is Home ICT?

As the next stage of the continuing expansion of next-generation network (NGN) services, new added-value services are now emerging. Among those that are attracting considerable attention are the home ICT services, where imaging devices, sensors, cameras, and other sophisticated home devices are linked and coordinated over the network. In the home ICT system, various home devices having different protocols are terminated at the HGW; and the HGW then coordinates with service servers within the network to provide various services including: home appliance interaction such as video sharing between remote users, home monitoring with sensors, remote support for IT devices, and health care.

1.2 Functions required for HGW

The home ICT must be able to deal with continually evolving home devices and services in a flexible manner. Thus, in addition to the telephone function (VoIP: Voice over IP) and broadband router function that are the basic functions of the NGN, the HGW is required to have a platform structure as shown in Fig. 1 that flexibly handles various services and protocols, as well as the OSGi™ [1] Service Platform that executes application programs delivered over the network.

The OSGi service platform can manage and dynamically install and execute multiple applications as individual pieces of bundled software.

In addition, since these dynamically installed home ICT services should not affect the lifeline services, the HGW is required to have a safety mechanism to protect the VoIP function from erratic behavior of the application programs manufactured by the service provider.

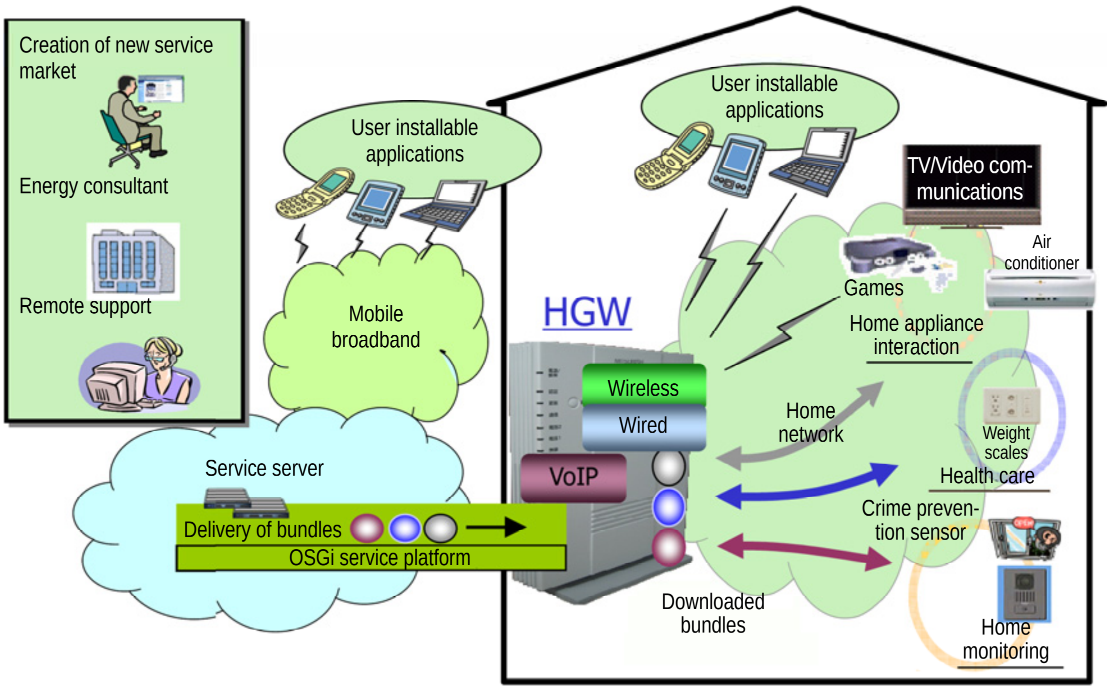

Fig. 1 Positioning of HGW in the Home ICT

[1] OSGi is a trademark or a registered trademark of the OSGi Alliance in the United States, other countries, or both.

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2. Architecture of HGW

2.1 Hardware architecture

In addition to the VoIP and broadband router functions that are the basic functions of NGN, the HGW is required to have a platform architecture that flexibly handles various services and protocols. To meet this requirement, we have developed a hardware architecture that makes it possible to configure and perform independent multiple functions on a high-speed packet forwarding engine that can transmit IP packets at a wire-rate speed of 1 Gbps.

2.2 Software architecture

The architecture patterns that were introduced in the Pattern-Oriented Software Architecture (POSA) series[2] are widely known in the software field. However, when we developed the HGW equipment, we defined our own software architecture considering the following requirements:

- Scalability
  To ensure the independence and scalability of individual functions for easy incorporation of rapidly evolving new technologies
- Portability
  To ensure portability to other devices. As an example, in an optical network unit (ONU) that has the HGW's telephone function, a new device can be realized by loading (plugging in) ONU-specific functions to the router and VoIP functions.

As shown in Fig. 2, the HGW's software architecture consists of four layers: a manager layer, a middleware layer, a service layer, and an application layer.

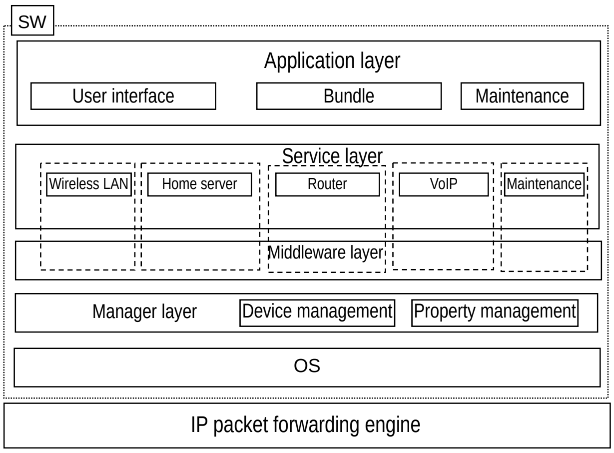

Fig. 2 Hardware architecture of HGW

(1) Manager layer

The manager layer consists of the device management block that performs device-specific hardware control and conflict control, and the property management block that provides the upper layers with a database function and a service coordination and arbitration function. The details of these functions are described in Section 3.1.

(2) Middleware layer

In close coordination with the upper layers, this layer provides protocol stacks for the upper layers to perform their functions.

(3) Service layer

The service layer coordinates all protocol stacks in the middleware layer to perform various HGW services for users:

a) Router service: As the core service of HGW, this service performs the broadband router function and additional carrier-specific services
b) VoIP service: Performs the analog fixed phone and IP phone function
c) Wireless LAN service: Provides the 802.11n function and other wireless LAN functions
d) Home server service: Provides the Digital Living Network Alliance (DLNA) service and other functional elements of home ICT
e) Maintenance service: Provides the carrier-specific maintenance function

(4) Application layer

This layer provides device setting and high-level application services using application programming interfaces (APIs) provided from the service layer:

a) User interface: Performs the setting and control of devices using the GUI and telephony functions.
b) Bundle: A bundle is an application that operates on the OSGi service platform, and fully utilizes the service layer to provide end users with connectivity and interoperability of home appliances, home monitoring, health care, and other home ICT services.

3. Technologies to Support HGW Architecture

3.1 Service Coordination and Arbitration Technology

The property management block is implemented in the manager layer to allow the HGW to deal with the expansion of various services and protocols in a flexible manner. The property management block provides the database function as well as the communication function to interconnect the services. The communication function enables each software component in the service layer to be plugged in, and thus accomplishes scalability and portability.

Referring to Fig. 3, an operational example is now described. The wireless LAN service and the VoIP service have placed a subscription request, in advance, to the property management block for any change in Property A, which they want to know. If the router service changes this property value, the wireless LAN and VoIP services are notified of the change and can perform appropriate processing as required. If a new device is developed without any wireless LAN capability, no subscription is requested from the service of this device, and thus the software can be configured without affecting other services. On the other hand, if a newly added service makes a subscription request, any property change is automatically notified.

The above-described mechanism is flexible enough in terms of scalability and portability; however, since all services are completely independent from each other, no arbitration can be made on the overall system operation. In order to implement an arbitration function for the overall system operation while retaining the good features of the property management mechanism, we tried to solve the problem by using a device conflict control matrix.

The device conflict matrix describes all conflict control conditions for the entire system, and is logically linked to the database in the property management block. Before any program in the service layer performs certain processing, the service layer asks the device management block whether or not this processing can be performed. The device management block then checks the device conflict matrix for the processing that the service layer wants to perform, and returns the result to the service layer.

Referring to Fig. 4, an operational example is described. The line for emergency calls (calls to the police, etc.) becomes busy and the VoIP service asks the property management block to set the emergency call prop-

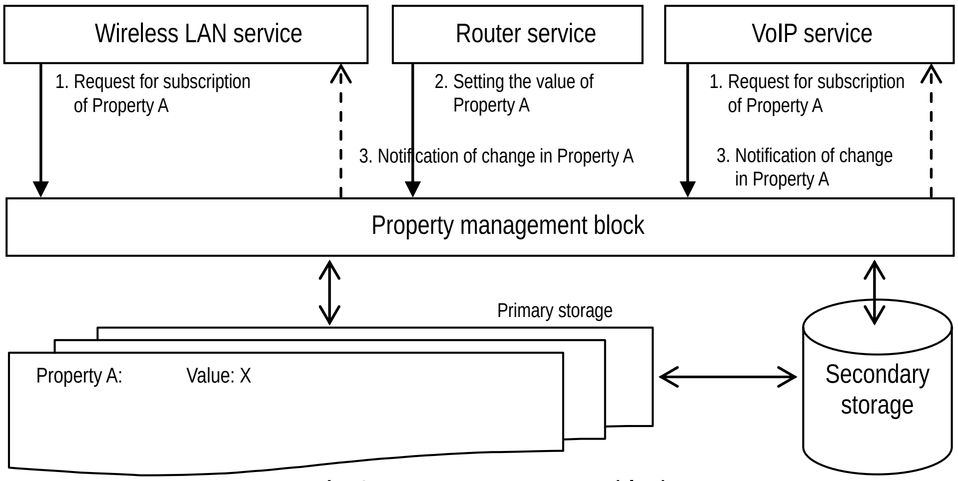

Fig. 3 Property management block

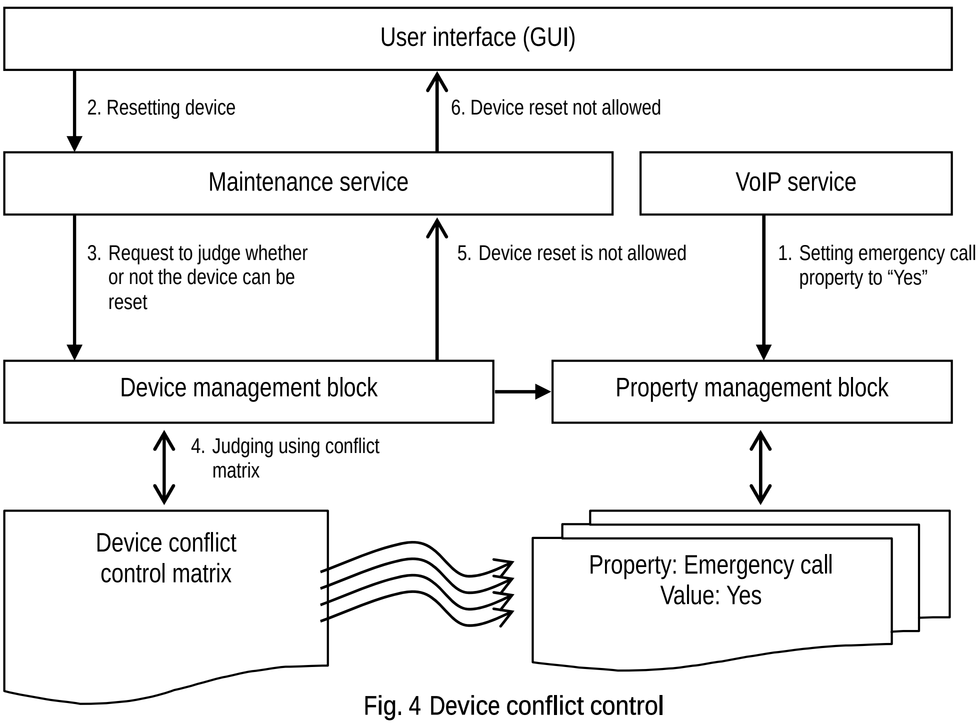

Fig. 4 Device conflict control

erty to "Yes." When a device reset request is eventually sent to the maintenance service via the user interface, the maintenance service asks the device management block whether or not the device reset can be performed. The device management block checks the conflict matrix and finds out that the emergency call line is busy, and then returns "Do not execute" to the maintenance service.

3.2 Robustness of VoIP

The bundle block in the HGW's application layer incorporates the virtual machine (VM) and OSGi service platform for realizing home ICT. In addition, a native interface (NI) is also implemented to provide HGW-specific functions that cannot be realized by the OSGi platform service only.

Various home ICT services are performed by bundles that operate on the above-mentioned platform provided by the HGW. Each bundle provides the target ICT service by using an HGW's various NI functions, e.g., the setting of various parameters and controls HGW. An individual bundle is manufactured by the application vendor based on the common disclosed API specifications. Further, those APIs run over HGWs manufactured by different equipment vendors. However, since these bundles are manufactured by a different application vendor, the HGW manufacturer vendor cannot control the quality of the bundle itself.

The bundle uses various resources within the HGW, e.g., the CPU, memory, and other resources of its own via appropriate NIs. If more than the necessary amount of resources is consumed due to erratic behavior of a certain bundle or other reasons, the VoIP may be directly or indirectly affected. Meanwhile, the VoIP that performs emergency calls is the home lifeline function. Therefore, the HGW architecture is required to prevent any abnormal operation of the bundle operating on the HGW from affecting the VoIP function.

Figure 5 shows a conceptual diagram of the HGW's bundle block and threat to the VoIP part.

Effects from a bundle's abnormal operations can be categorized as follows:

(1) The quality of VoIP communications is degraded due to the occupation of the CPU.
(2) The processing by the VoIP fails due to excessive memory consumption.
(3) The quality of VoIP communications is degraded due to the occupation of resources in the service and lower layers caused by continual NI calls from the bundle.
(4) Various resources are not released when the VM is forced to terminate due to erratic behavior of the bundle. When the VM is restarted, the processing by the VoIP fails due to the effect of the unreleased resource.

To deal with these threats to the VoIP, we took the following preventive measures:

[Preventive measure 1]

The OS of the HGW can set the priority of each process. By setting a high priority to the VoIP and low priority to VM processes, sufficient CPU resource is secured for the VoIP to prevent the quality of communications from being degraded.

[Preventive measure 2]

The VM is designed to set the maximum memory size and not to allow any memory allocation beyond this size. Threats due to memory shortage are prevented by this mechanism.

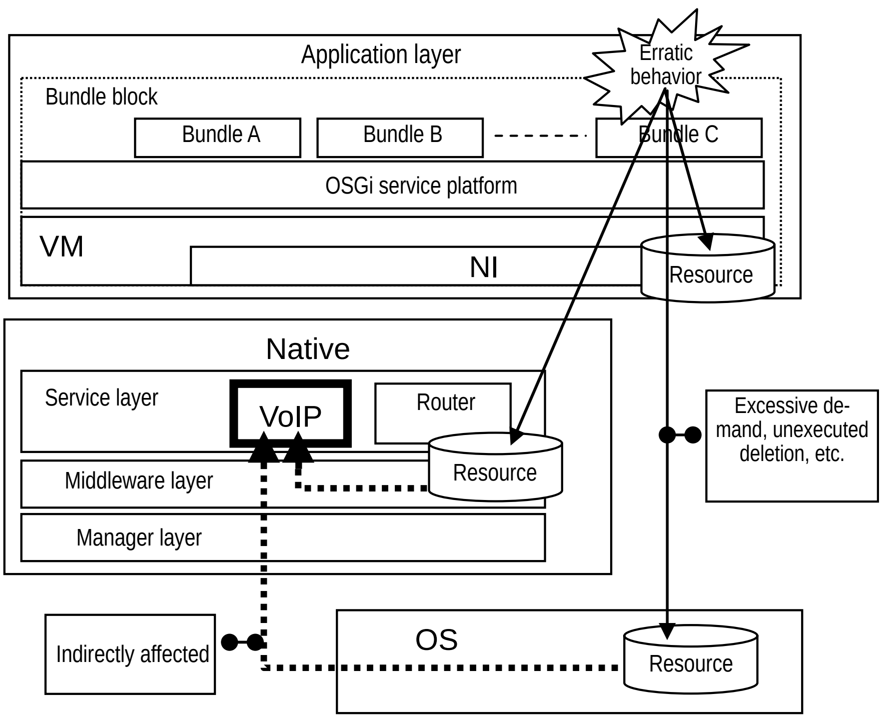

Fig. 5 Architecture of bundle block and threat to VoIP

[Preventive measure 3]

A monitoring mechanism for NI calls is implemented to limit the calling frequency up to N times/s. By setting this NI guard mechanism, even if a runaway bundle continually attempts to call the NI, the VoIP is not affected.

[Preventive measure 4]

The property management block described in 3.1 manages the start and stop of each VM process. Meanwhile, each program in the service layer, which reserves various resources in response to requests from the bundle, sends a subscription request to the property management block for notification of any change in the start/stop status of the VM process. When the VM stops, the property management block issues a status change notice to all the programs from which the subscription was requested. Each program that has received the notice recognizes the stop status and releases various resources that are no longer necessary after the termination of the VM process. These measures prevent any adverse effect on the VoIP from unreleased resources.

3.3 High-speed packet forwarding technology

As home network devices improve in performance, the HGW is also required to enhance its processing capacity. In response, a high-speed packet forwarding scheme for the HGW has been developed using the fast-path forwarding control. In the fast-path forwarding control, any flow creation or deletion by the OS-standard flow-based management mechanism is externally monitored by the monitoring function in the flow management mechanism, and when any flow creation or deletion is detected, it is registered in the mechanism of the IP packet forwarding engine. When a packet belonging to a registered flow is received, it is processed by the IP packet forwarding engine using the dedicated high-speed forwarding function, not the protocol stack in the OS (Refer to Fig. 6). The HGW can recognize a sequence of IP packets as a flow by identifying the format {Source/Destination IP addresses, Protocol, Source/Destination TCP/UDP port numbers}.

4. Prospects for the Future

The newly developed HGW equipped with an OSGi platform is able to perform various home ICT services. We will work on the expansion of this HGW for the next-generation home ICT services and apply the developed technologies to other equipment.

Lastly, we express our deep appreciation to those who provided tremendous guidance in our development project.

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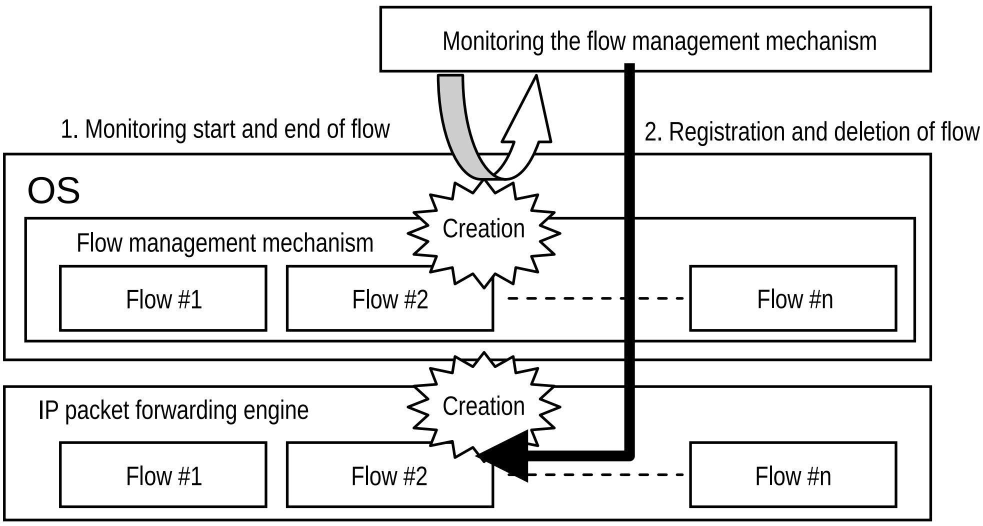

Fig. 6 Concept of fast-path forwarding control

Approach to IP-STB

Authors: *Shin Miura** and *Hiroyuki Ojima***

1. Introduction

Full-scale next-generation network (NGN) service has already started, and the development of broadband and high-reliability network infrastructure is in progress. Meanwhile, the number of network-connectable household devices such as personal computers (PCs), audio visual (AV) equipment, and home security equipment continues to increase. Home information and communication technology (ICT) provides users with new services by linking the customer premises equipment with the network.

Mitsubishi Electric has been working on the development of key technologies required to realize the home ICT, including: Home Gateway (HGW), Internet Protocol Television (IPTV) technology, and Digital Living Network Alliance (DLNA) compliant home network technology.

This paper describes Mitsubishi Electric's approach to ICT, centering on IPTV technology that makes it possible to enjoy video streaming services.

2. Trends in the IPTV Industry

Domestic IPTV services are largely divided into two categories: those provided over the controlled Content Delivery Network (CDN) that uses a highly reliable network such as NGN, and those provided over uncontrolled Internet services. The former service mainly assumes an optical line as the access network to provide high-quality Hi-Vision video content, and its subscribers have already exceeded two million. In addition, because of its high reliability, an IP retransmission service for Digital Terrestrial Broadcasting (DTB) has also been provided since May 2008, and another IP retransmission service for Broadcast Satellite (BS) broadcasting has started since October 2010. Meanwhile, Internet-based IPTV services, such as "acTVila" sponsored by the home appliance industry and user-contribution-type video sites, are also spreading. By making the best use of the interactive features of IPTV, more new services are expected to emerge in the future.

3. IP-STB

3.1 Approach to the development of IP-STB

As IPTV is an important technology for combining communications and broadcasting, Mitsubishi Electric has been working since 2006 to further develop IPTV based on its own technologies for optical communications, video encoding, and AV home appliances. As a result, an IP set-top box (IP-STB) has been developed for receiving and playing IPTV service programs. In 2007, pioneering the industry, we successfully cleared the guideline for the retransmission of DTB. We also participated in an NGN trial conducted by the communications carrier. In 2008, we delivered our IP-STBs to the IPTV carrier for their internal evaluation. After that, the system-on-a-chip (SoC) was upgraded to the latest version; more compact size and lower power consumption have been achieved; and in May 2010, the first commercial products were released.

3.2 Outline of IP-STB

In May 2010, Mitsubishi Electric launched the IP-STB shown in Fig. 1, which is in compliance with the IPTV forum specifications and can receive and display Hi-Vision quality video content delivered over the CDN configured with the NGN.

Fig. 1 External appearance of IP-STB

This IP-STB covers the services of IP multi-channel broadcasting, IP retransmission of DTB and BS broadcasting programs, and video on demand (VoD). In addition, broadcasting content can be recorded and replayed maintaining the Hi-Vision quality to/from an external hard disk drive via a universal serial bus (USB) port.

This IP-STB makes it possible for the service provider to supply the service menu screen on-line, for example, for the user to select the desired video content, rather than pre-installing it as embedded software; and thus the provider can easily add and/or change the service menu. Regarding the recent topic of 3D broadcasting service, this IP-STB already covers the side-by-side method with half-HD quality, and 3D broadcasting can also be enjoyed by connecting it to a

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Table 1 Functional overview of IP-STB

Item	Description
IP version	Hybrid of IPv4 and IPv6
Transmission protocol	IP/UDP/RTP
Multiplexing system	MPEG-2 TTS
FEC	Pro-MPEG CoP3 1D/2D
IP broadcasting channel selection	MLDv2 (IPv6), IP multicast
VoD control	RTSP, IP unicast
Video coding	MPEG-2 MP@ML, MP@HL MPEG-4 AVC (H.264) MP/HP Level: 3/3.1/3.2/4
Voice coding	MPEG-1 Layer2, MPEG-2 AAC-LC
Subtitle ES	Available for IP broadcasting, VoD, DTB/BS Retransmission
BML browser	For data broadcasting
Reservation function	Viewing reservation and Recording reservation are available
Video recording	Digital recording on USB external HDD (TS recording)
Trick play	Fast forward, Fast reverse, Pause, Skip chapter
Configuration information	Available for IP-B, VoD, DTB/BS Retransmission
Program guide	Program guide/ Competing program guide for IP broadcasting, DTB/BS Retransmission Display control of adult service for IP broadcasting
3D display	Side-by-side method (Half-HD quality) (TV set needs to be manually set to 3D mode)

UDP: User Datagram Protocol
RTP: Real-time Transport Protocol
TTS: Timestamped Transport Stream
FEC: Forward Error Correction
CoP: Code of Practice
MLD: Multicast Listener Discovery
RTSP: Real Time Streaming Protocol
AVC: Advanced Video Coding
AAC-LC: Advanced Audio Coding-Low Complexity
ES: Elementary Stream
BML: Broadcast Markup Language

3D TV set with a High-Definition Multimedia Interface (HDMI) cable.

The functional overview and main specifications of the IP-STB are shown in Table 1 and Table 2, respectively.

Table 2 Main specifications of IP-STB

Item	Description
LAN terminal	10/100Base-TX (RJ-45) × 1
Video output terminal	HDMI 1.3a × 1
	Component (D3) output × 1
	Composite output × 1
Audio output terminal	Line (L/R) output × 1
	Optical digital (5.1ch) output × 1
HDD port for recording	USB 2.0 × 2
Power supply	AC100V/50-60Hz AC adaptor
Power consumption	Normal: 8.7W (VoD viewing), Standby: 6.7W, Sleep mode: 0.7W
External dimensions	(W) 200 mm, (D) 150 mm, (H) 30 mm
Weight	350 g (main body only)

4. Approach to the Future

4.1 Home network interoperability

Increasingly more digital TVs, Blu-ray recorders, and other devices from major domestic AV device manufacturers are equipped with DLNA-based home network connectivity. Many PCs and network-attached storage (NAS) HDDs are also DLNA compatible. There is a growing trend in content sharing between home networked devices. Since 2003 when the DLNA was established, Mitsubishi Electric has been involved in the standardization and R&D activities of DLNA. At the Plugfest interoperability event hosted by the DLNA, the developed DLNA middleware was tested to enhance the interoperability. In May 2011, a new IP-STB product

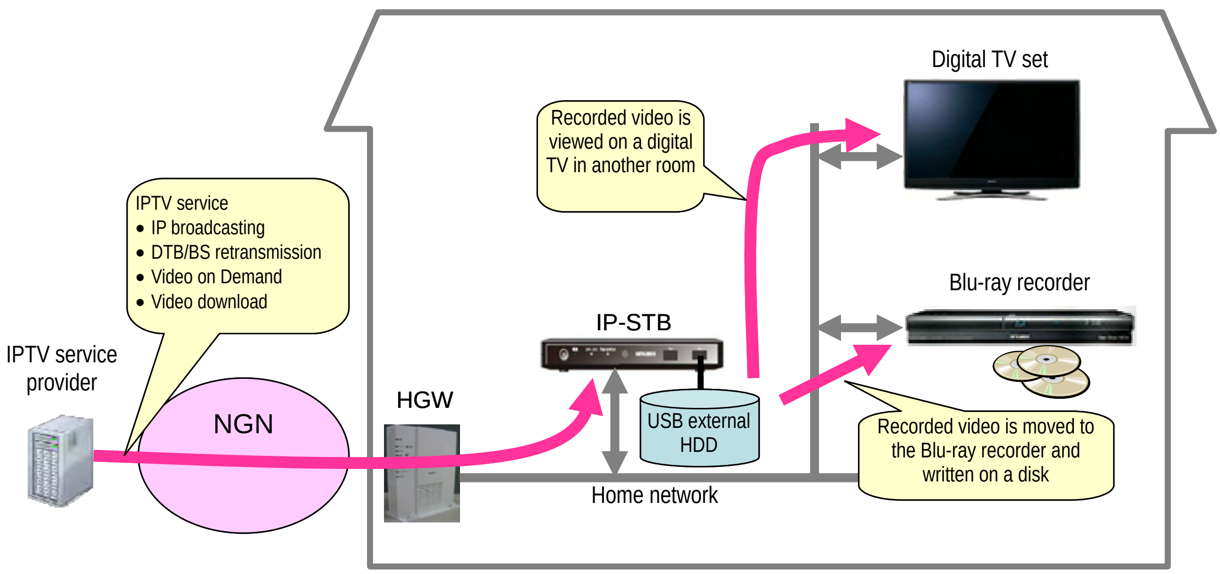

Fig. 2 DLNA-based home network interoperability

was developed with home network connectivity and interoperability. Figure 2 illustrates an example of the home network interoperability of this IP-STB.

4.2 Interactive service support

By making full use of its interactive features, IPTV is expected to provide various new services including: TV commerce, remote education, security service, and remote healthcare. Mitsubishi Electric is considering the use of widgets as one approach for realizing an environment that allows for easy installation and execution of various applications on the IPTV set, that is, a platform for flexibly performing these services.

A widget is a small Java script application that links to web information. Mitsubishi Electric is conducting research and development on a compact widget execution environment for embedded devices, which makes it possible to run widgets in compliance with the industry standard World Wide Web Consortium (W3C).

4.3 Reducing Power Consumption

Reducing power consumption is a recent attention-attracting topic. Mitsubishi Electric has optimized the standby mode, and in addition to the power-saving standby mode (power saving by 90%), has developed a new standby mode (power saving by 20%) with a reservation start and quick start (within 5 s) function, which encourages power saving in accordance with the use scene. We plan to further reduce the power consumption by adopting the latest SoC, and further optimize the standby mode for additional power saving. In addition, we are also considering linking various customer premises equipment centering on the HGW, and collecting real-time power usage conditions through the HGW for displaying on the TV monitor.

5. Conclusion

This paper described the IPTV service, one of the representative home ICT services, specifically the trends in service and standardization, and Mitsubishi Electric’s IP-STB. We will continue working on technology development to provide users with convenient and easy-to-use home ICT services. In parallel, we will also pursue lower power consumption and total energy saving at home by achieving connectivity and interoperability of the equipment.

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