Development of Next Generation Optical Access Systems

Yoshikazu Fujita Akihiro Takahashi
Takeshi Koike Akiya Suzuki Kazumi Onishi

Centered on the Fiber-to-the-Home (FTTH) service, the number of broadband service users in Japan has shown steady growth and has surpassed 20 million[1]. Due to the expansion of video services such as Internet Protocol Television and proliferation of smartphones in recent years, downstream traffic volume has also increased substantially, up 22.6%[2] compared with previous fiscal year. Presumably there will be a growing demand for broadband optical access lines in the coming years.

Additionally, the diversity in broadband services such as remote medical care/diagnosis that requires high-quality and high resolution image transmission, and video conferencing that demands real-time communications have been increasing the need for broadband.

On the other hand, after the conclusion of the Kyoto Protocol, efforts have been made to fight global warming and achieve a low-carbon society. In June 2009, the Telecommunications Carriers Association and four other organizations joined to launch the "ICT Ecology Guideline Council" and announced a voluntary standard titled "Ecology Guideline for the ICT Industry"[3]. The guideline includes evaluation criteria with five levels depending on the power consumption. The number of customer premises equipment (ONU: Optical Network Unit) in the network is enormous and is found to consume 60% of the total power[4]. Therefore, power-savings in accordance with the above guideline is highly anticipated.

Furthermore, in order to close the digital divide, economical deployment of optical access networks is being sought in rural areas and other regions where optical infrastructures are underdeveloped. Long distance transmission technology for optical access is desirable as it will reduce the facility maintenance costs and energy usage by bypassing the transit facilities. In urban regions, long distance transmission technology can be utilized for multi-branching to efficiently accommodate users in densely occupied areas such as an apartment complex.

As for international standardization of 10Gbps-class optical access systems, IEEE's work on IEEE802.3av (10G-EPON) was finished in September 2009, and ITU-T/FSAN completed its standard on XG-PON1 (G.987) in June 2010. Although ITU-T defines all necessary layers, IEEE802.3av/802.3ah (GE-PON) only defines the PHY and MAC leaving carriers and vendors to use proprietary specifications at the EPON system level. Therefore, in 2009, IEEE launched P1904.1 (SIEPON) to standardize the system and network level, as well as sections that were not defined in IEEE802.3. The drafting of conformance test specification (P1904.1/Conformance) started in 2011. Currently the work is progressing with P1904.1 (SIEPON) slated for completion in February 2013 followed by the conformance test specification in December 2013.

Given this background, we are actively engaged in the development of a power-saving, long distance, broadband optical access system that covers the home network as well.

Energy Efficient Optical Access

(1) Power-Saving with Next Generation ONU

In order to work toward an energy efficient GE-PON ONU, a new power-saving technology was developed for the next generation ONU. The goal was to achieve power-savings at the hardware level while retaining functionalities of the current ONU. Development included the following:

1. Utilizing fine-process on the main LSI/IC;
2. Optimizing the high-speed serial interface circuit;
3. Improving the efficiency of the power unit.

Firstly, in the course of fine processing on the main LSI/IC, the PON-LSI and PHY-IC, which performs physical layer termination at the UNI-side, were developed in-house using fine process. A new PON-LSI was developed to comply with the power-saving standard described later in order to meet further requirements in power-savings. Secondly, to optimize the high-speed serial interface circuit, the circuit configuration of the high-speed serial interface between PON-LSI, which performs PON-IF MAC layer processing, and the optical termination unit was modified to be more energy efficient. Thirdly, AC adapter and power circuits that generate internal ONU voltages were optimized to improve the efficiency of the power unit (**Figure 1**).

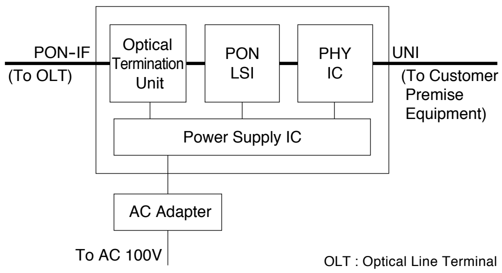

Figure 1. GE-PON ONU Block Diagram

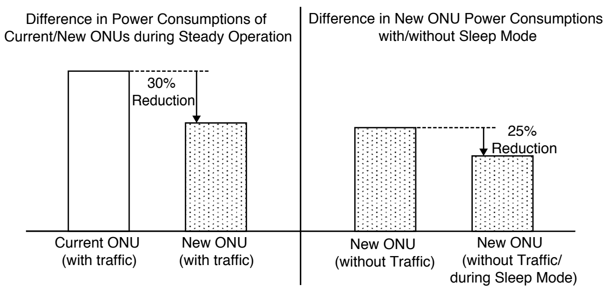

Figure 2. Power Consumption Changes in GE-PON ONU

As a result of the three improvements above, the power consumption was reduced by approximately 30% compared with that of current ONU (**Figure 2**). The new ONU also achieved a 5-star rating, which is the highest rank in GE-PON ONU evaluation according to the "Ecology Guideline for the ICT Industry (Version 2)". If the FTTH subscriber equipment deployed as of 2011 was switched from its current ONU to the newly developed ONU, the yearly reduction of CO_2 would be about 90,000 tons which is equivalent to the amount of CO_2 absorbed by 6.5 million cedar trees[5)].

Furthermore, the power consumption of the new ONU is within the power-supplying capability of the Universal Serial Bus (USB). If an ONU that operates on USB power from a battery-operated laptop PC is available, Internet access can be maintained even in times of disaster or rolling blackouts ensuring people have the means to access safety and other vital information.

(2) Power-Saving with Sleep Mode

In addition to power-saving measures at the device and circuit level, sleep modes were implemented at the system level for further reduction in power consumption. Various sleep modes can be supported through changes in the new ONU's firmware.

1) Power-Saving with UNI-side Sleep Mode

On the UNI-side, power-saving is achieved by turning on/off sleep mode according to traffic conditions. The mode is controlled using a LPI (Low Power Idle) signal sent from the PON-LSI to the PHY IC, which is IEEE802.3az compliant.

2) Power-saving with PON-side Sleep Mode

The previously mentioned IEEE P1904.1 (SIEPON) suggests the power-saving feature, in which OLT and ONU go into sleep mode, and ONU periodically turns the power off and on at the locations where sleep mode is enabled. For the ONU's sleep locations, Tx mode and TRx mode are defined. Tx mode puts a transmitting-side to sleep, and TRx mode puts both the transmitting and receiving side to sleep. **Figure 3** shows an overview of the ONU sleep operation. OKI has developed an IEEE P1904.1 (SIEPON) Draft 2.0 compliant sleep mode, which achieved power-saving on a system where 10G-EPON OLT, 10G-EPON ONU, and GE-PON ONU coexist.

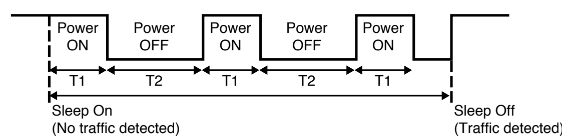

Figure 3. IEEE P1904.1 Sleep Operation Overview (Example)

Besides those defined in the standards compliance above, a sleep mode that can be operated solely by ONU has been under development. These various sleep modes enable power reduction of approximately 25% when there is no traffic (**Figure 2**). Future work will include the study of power-saving operation under various advanced parameters taking into account impact on services such as latency when power-saving functions are activated.

Measures for Expanding Optical Coverage

(1) Expansion Issues

In expanding optical coverage to rural and other underdeveloped regions, there were several issues with the PON-leg (between OLT and ONU) of the GE-PON that needed to be resolved including increased signal loss in the optical transmission path and wavelength dispersion effect of the Fabry-Perot laser diode. These issues were too great to ignore.

(2) Development of High-Speed GE-PON Optical Transceiver

To solve the issues above, a new high-performance optical transceiver was developed. It provides small wavelength dispersion effect and large "optical power budget", defined by the difference between transmitter output and received optical sensitivity at the receiver, was developed.

The following three new technologies were applied to the development of the high-performance optical transceiver.

1. Optical transmitter: use of non-spherical lens to improve coupling efficiency
2. Optical transmitter: use of distributed feedback laser diode to increase output
3. Optical receiver: use of avalanche photodiode (APD) to achieve high receiver sensitivity

These technologies made it possible to expand the optical power budget within the PON-leg thereby enabling optical service to be provided to areas farther than 20km.

(3) Long-Distance Transmissions with Next Generation Access Systems

Of the wavelengths defined by IEEE802.3av, the OLT 10G downstream transmission wavelength is in the 1577nm band that is susceptible to wavelength dispersion making long-distance transmission difficult. Wavelength dispersion is often dealt with using dispersion compensating fiber or electronic dispersion compensation (EDC).

For a PON system application, it is not practical to lay down dispersion compensating fiber depending on the distance of the ONU. EDC, which compensates distance-dependence at the IC, is the better option.

Downstream 100km transmission has been confirmed using prototype EDC function based on a Maximum Likelihood Sequence Estimation (MLSE), via a 100km fiber between the OLT and ONU. In the future, equipping ONU with EDC function will be studied according to market demand.

Broadband Optical Access

(1) Development of 10G-EPON System

As growth in network traffic calls for broadband access, OKI developed 10G-EPON system compliant with IEEE 802.3av as a successor to the GEPON.

10G-EPON system is composed of OLT and ONU. It is possible for 10G-EPON ONU and GE-PON ONU to coexist under the OLT (**Figure 4**). The downlink of the PON-leg uses wavelength division multiplexing (WDM) with 1577nm 10G and 1490nm 1G wavelength signals while the uplink uses time division multiple access (TDMA) with 1270nm 10G and 1310nm 1G signals, which are in the same wavelength band.

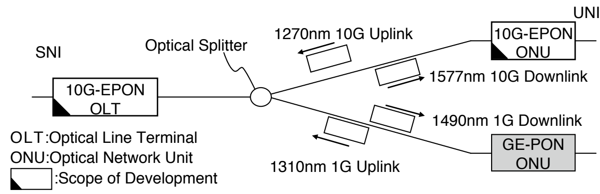

Figure 4. Example of 10G-EPON System Configuration

(2) Features of the 10G-EPON System

The OLT and ONU of the 10G-EPON system have the features 1) through 3) described below. Block diagrams of the system are shown in **Figure 5** and **Figure 6**.

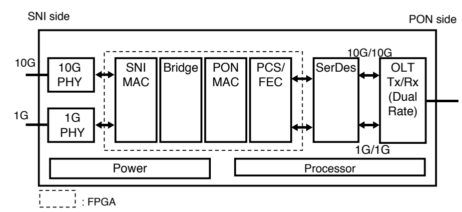

Figure 5. Block Diagram of 10G-EPON OLT

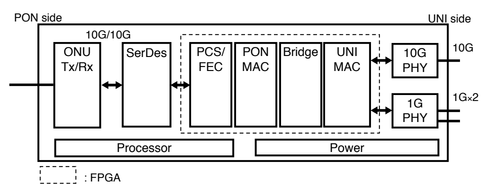

Figure 6. Block Diagram of 10G-EPON ONU

1) Dual-rate Burst Reception Performance of OLT

OLT of the system is required to meet IEEE802.3av PR30 specifications even at times when 10G-EPON ONU and GE-PON ONU coexist within the same Optical Distribution Network (ODN). For this reason, optical transceiver (OLT Tx/Rx) equipped with high-sensitivity APD-TIA that includes a burst Transimpedance Amplifier (TIA) capable of dual-rate reception was adopted and combined with burst SerDes that has a built-in 10Gbps burst CDR to ensure the required loss budget.

2) Coexistence Operation of 10G-EPON ONU and GE-PON ONU

To allow the coexistence of 10G-EPON ONU and GE-PON ONU, and contribute to a smooth migration, Dynamic Bandwidth Allocation (DBA) algorithm was developed using a proprietary method.

Multi-Point Control Protocol and DBA functions that detect the multiple ONUs in a user's home and connect them to the OLT are software processed to allow flexible parameter/algorithm changes.

3) Accommodation of Multiple ONU Logical Links

Each ONU in the system accommodates multiple logical link IDs (LLIDs), and each LLID can be allocated to and used by several users. This enables a single ONU to be shared with multiples users, thus cutting equipment costs.

It is also possible to provide multiple services to a single user and offer flexibility in the services provided.

Initiatives for Optical Access and Home Network

(1) Home Network Configuration

Home network connects not only PCs in a home environment, but also other non-PC devices such as AV equipment, home appliances, housing equipment and sensors. Linking the home network with the backbone network enables interaction between the in-home devices and backbone network to provide new ICT services that can be enjoyed at home such as home energy management, media sharing, remote support of in-home devices, home security, and remote medical care. **Figure 7** shows a devices configuration which will allow the use of these home ICT services.

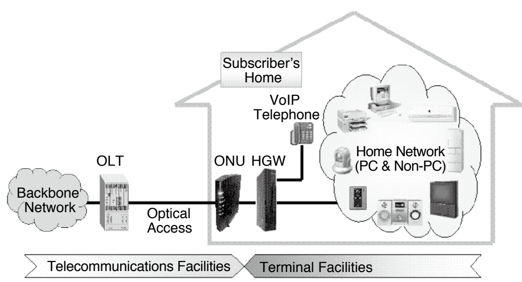

Figure 7. Home ICT Service Configuration

In order to connect the home network to the backbone network, an ONU and home gateway (HGW) are required at the boundary.

Unlike PCs or AV equipment, ONU and HGW do not require direct interaction from the user, and potential need is greater for compactness and integration. On the other hand, as a mean to support new functions, it is desirable to keep the ONU and HGW separated to allow independent upgrades of the equipment since HGW evolves much faster than the ONU.

(2) Prototype of a Compact ONU Module

One way to physically separate the ONU and HGW, but at the same time achieve compactness and integration is to implement the ONU function into a compact module then insert that module into an mounting slot in the HGW for integrated operation.

In such a configuration, compactness of the ONU will be the key. Therefore, a prototype ultra-compact ONU module for GE-PON was built to confirm feasibility.

To take into account versatility, the implementation and electrical interface requirements follow the slot-in module specifications as defined in the GBIC standard.

The size of the prototype is 30.5 [W] × 10.0 [H] × 65.3 [D] mm, and the volume is 1/35 of conventional ONUs (**Photo 1**).

Photo 1. Prototype of GBIC ONU

Three major changes from the conventional stand-alone ONU enabled the compact design of the new ONU, and they are listed below.

1. Adoption of a mini BGA package LSI to reduce mounting space
2. Adoption of a board with built-in components to reduce board area
3. Use of BOSA on Board for the optical module to reduce size

Even if there is no home networking, the compact ONU can be directly mounted in a slot of a device such as an IP-TV to provide service without unsightly equipment ruining the interior décor.

(3) Future Efforts

The prototype was an application of the GBIC standard, but in the future, we plan to incorporate the latest technical trends for a more versatile modular ONU.

Conventional stand-alone ONU will also be upgraded with a variety of interfaces and functions such as Wi-Fi, G.hn and VoIP to support various placement and operational situations at the customer premise. ◆◆

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Authors

Note: Titles and organizations are current as of March 2012

Yoshikazu Fujita, Research and Development Department Access System B, OF Networks Co., Ltd.

Akiya Suzuki, Research and Development Department Access System B, OF Networks Co., Ltd.

Akihiro Takahashi, Research and Development Department Access System A, OF Networks Co., Ltd.

Takeshi Koike, Research and Development Department Access System A, OF Networks Co., Ltd.

Kazumi Onishi, Research and Development Department Access System A, OF Networks Co., Ltd.