WDM/TDM-PON High Functionality Transceiver Technology for High-quality, Low-power Consumption Optical Access Network

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As a solution to the energy/environmental and aging population problems, Japan's attention is focused toward the creation of smart communities. R&D and operation tests are already underway to bring the smart communities to fruition. When realized, smart communities promise a safe and comfortable society. For instance, in a smart community, data on changes in electrical supply and demand can be collected. Then power including dispersed energy sources such as solar cells can be controlled to optimize usage. Another example is the monitoring of the elderly. Each elderly person's environmental conditions can be individually monitored to provide exact services he/she requires. However, to achieve such communities, a communication infrastructure that includes a next generation access network is necessary.

The above-mentioned communication infrastructure will need flexibility to meet various requirements and have broadband capability to cope with applications that handle large volumes of data such as video distribution. Furthermore, as mobile access becomes the future mainstream access, there will be an explosive increase in the number of mobile terminals and traffic. In response, fusion of optical and radio to accommodate the densely deployed wireless base stations into the optical access network is desired, and flexible, high-quality network is expected. Since faster speed of the communication devices increases power usage, minimizing the system power consumption is also an important issue.

To achieve the communication network described above, OKI is engaged in the research and development of a high-quality/low-power consumption optical radio fusion network based on WDM/TDM-PON. This article presents an image of the future network that will serve as the next generation communication infrastructure and introduces the WDM/TDM-PON system and high functionality transceiver technology that will be necessary.

High-quality/Low-power Consumption Future Network

OKI's image of the future network is shown in **Figure 1**. The core network will need to be flexible (SDN core network) with nodes (router/switches) configured virtually using software functions. In addition, the explosive spread of faster mobile terminals and the progress of "Internet of Things (IoT)" will increase the flow of traffic through the core network. Therefore, it is more effective for the Data Center (DC) cloud servers to take on a distributed configuration using local servers. With the coordinated operation of the cloud servers and local servers, the virtual network will be able to suppress traffic flow through the core network and control delays.

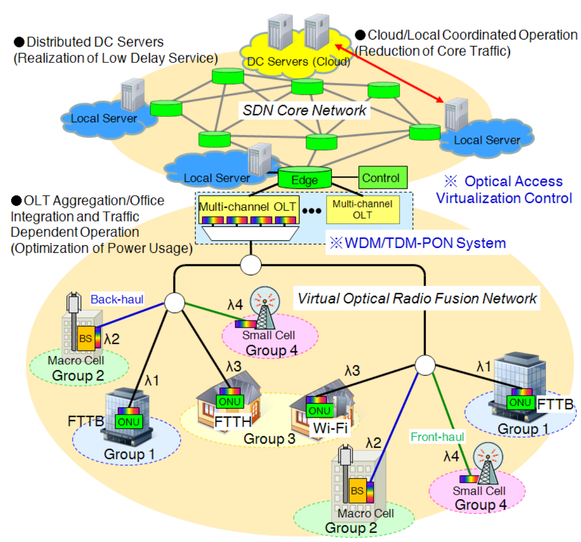


Figure 1. Future Network Image

At the access area, if accommodation of mobile traffic into the optical access network is considered, there will be significant fluctuation in the traffic a single device will process depending on the time of day. In such a case, virtually controlling bandwidth and devices will enable efficient operation of the network.

Since WDM/TDM-PON can be assigned a bandwidth by wavelength and time, group management is possible for each service. For example, flexible grouping by wavelength and time domains can be performed depending on the traffic volume such as for business, consumer or mobile. Then controlling the number of accommodated ONUs according to traffic that occurs daily and controlling the number of operating OLTs, power consumption can be reduced.

Power consumption of mobile terminals, which use mobile circuits (LTE, etc.) or fixed access circuits (Wi-Fi, etc.), varies by distance to the access point and by access method. To reduce power consumption, pathways are connected optimally taking into consideration terminal location, number of terminals within an area and communication capacity of each terminal[1].

WDM/TDM-PON System

Standardization of WDM/TDM-PON is already underway in G.989 of the International Telecommunication Union's Telecommunication Standardization sector (ITU-T), and OKI has been actively making proposal based on developmental results. The main specifications of G.989 are shown in **Table 1**. Specifications of G-PON/XG-PON are also shown for comparison.

Table 1. Main Physical Specifications of Various PON Systems

		Specifications		
		G.989 TWDM-PON	G.987 XG-PON	G.984 G-PON
Speed	Downstream	10Gbps	10Gbps	2.5Gbps
	Upstream	2.5Gbps /10Gbps	2.5Gbps /10Gbps	1.24Gbps /2.5Gbps
Waveband	Downstream	1596-1604nm	1575-1580nm	1480-1500nm
	Upstream	1524-1540nm	1260-1280nm	1260-1360nm
Number of Wavelengths		4 or 8	1	1
Wavelength Spacing		100GHz	-	-
Number of Branches		64 or more	32	32
Transmission Distance		40km or more	20km	20km

The basic speed in G.989 is the same as XG-PON (G.987) at 10Gbps, but the number of wavelengths is increased to four or eight achieving an overall capacity that is four times or more (40Gbps or more) compared with XG-PON. Waveband is set in a band that is unused to enable coexistence with previous PON systems. The WDM/TDM-PON's multi-channel OLT allows for flexible use of the multiple wavelengths. Hence, the 40Gbps bandwidth (with four waves) can be efficiently allocated according to network usage. On the other hand, in view of OLT aggregation and office integration, specifications call for multi-branching/long reach, which will require optical launched power and sensitivity to be raised. Unfortunately, current devices are already being used close to their characteristic limits, and further improvement is difficult.

Therefore, the use of optical amplifiers to boost, relay or pre-amplify the optical signals was considered. However, since relay type devices are placed in the middle of optical distribution network, issues of power supply and operational maintenance must be addressed.

From the above, OKI is studying the feasibility of implementing a booster and optical preamplifier in the OLT device as an advanced transceiver functionality to realize multi-branching and long reach.

High Functionality Transceiver Technology

In a PON system, since the TDM multiplexes ONUs situated at different locations, the upstream optical signal is a burst-mode signal. This requires that the optical amplifier used for high budget be a burst-mode type amplifier. Furthermore, optical fiber transmission is affected by non-linearity and when transmitting over long distances, waveform degradation occurs due to wavelength dispersion. The results of the study conducted on burst-mode optical amplifiers and the experimental results of transmissions with waveform shaping process are described below.

(1) Burst-mode Optical Amplifier

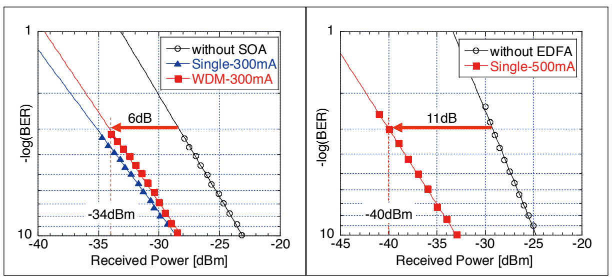
Erbium-doped fiber amplifier (EDFA) and the semiconductor optical amplifier (SOA) are two types of optical amplifiers. EDFA is a general-use optical amplifier and amplifies the C-band (1530nm~1560nm) and L-band (1560nm~1600nm) wavebands. SOA is used for optical switching, etc. and is capable of amplifying any wavelength depending on the device structure.

As previously mentioned, PON system communicates point-to-multipoint connections with TDM, thus each ONU generates burst signals. The wavelength used is 1260nm~1625nm. Accordingly, optical amplifier for a PON system requires consideration of burst mode and wide waveband.

1) Optical Preamplifier System

With SOA, occurrence of optical surge (hereinafter referred to as surge) is not a problem even with burst signals due to the short lifespan of excited state particles, but waveform degradation caused by pattern effect occurs. The SOA size is that of a semiconductor chip enabling integration with other optical components, thus it is suitable for miniaturization. The effect of using SOA in an optical preamplifier is shown in **Figure 2 (a)**. The figure shows the measured bit error rate (BER) with the SOA placed immediately before the receiver[2]. When SOA is used, minimum sensitivity of -34dBm@10-3 can be realized and an improvement of approximately 6dB can be observed. However, another issue with SOA is the large noise factor (NF). For further improvements, NF needs to be reduced.

On the other hand, NF is small with the erbium-doped fiber amplifier (EDFA), but lifespan of the excited state particles is long. With no input signal, energy from the excitation light remains in the fiber, and when a burst signal is input, a surge occurs. To combat the problem, a burst EDFA was developed. In this method, when there is no signal input, clamp light is introduced to remove the accumulated energy. Wavelengths that can be amplified are 1530-1560nm (C-band) and 1560-1600nm (L-band), which correspond to the wavelengths of G.989. This burst EDFA was used to evaluate the effect of an optical preamplifier. Although the evaluation system was similar to the SOA, due to fact that EDFA is a collective multi-wavelength amplifier, only the performance of a single wavelength was evaluated[3)]. The BER measurements are shown in **Figure 2 (b)**. The minimum optical sensitivity was improved to -40dBm@10-3 (improvement of approximately 11dB), which was 5dB better than the SOA.



(a) SOA (b) EDFA

Figure 2. Effects of Optical Preamplifiers

2) Booster System

If SOA is used as a booster after the optical modulator, the strong optical signal entering the SOA from the modulator will cause a pattern effect leading to waveform degradation. A function to suppress the pattern effect becomes necessary and sufficient output cannot be produced. Oppositely, if the signal is boosted with the SOA before the optical modulator, pattern effect will not occur, but output will again not be sufficient since modulation takes place after the boost. In both configuration, the output will be about +10dBm.

The burst EDFA, on the other hand, is not affected with pattern effect when used as a booster. Hence, the input/output characteristics were measured with wavelengths from 1598nm to 1575nm (downstream direction). The results are shown in Table 2. BER measurement taken at the wavelength with the highest output has confirmed that there is no transmission penalty.

From the results above, placing the booster and optical preamplifier only on the OLT side produced a budget*[1)] of more than 40dB in both the downstream (send +12dBm/receive -28dBm) and upstream (send 0dBm/receive -40dBm) directions. Consequently, it can be observed that the previous 32 branches can be increased to a multi-branching of over 256 branches.

Table 2. Input/output Characteristics during Booster Mode

Input	Output			
	1575nm	1580nm	1596nm	1598nm
-5dBm	+16.5dBm	+14.8dBm	+12.5dBm	+12.2dBm
0dBm	+17.2dBm	+16.5dBm	+15.9dBm	+15.0dBm

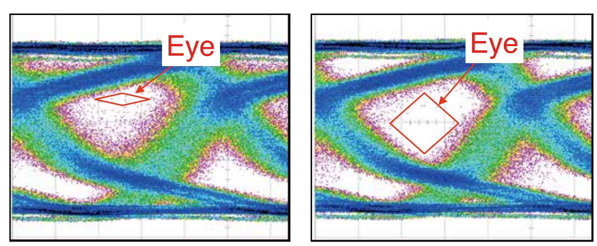
(2) Transmission Experiment to Confirm Effectiveness

The currently laid out optical fiber is 1.3μm zero dispersion. If 1524nm~1604nm optical signals defined by the International Standards G.989 is transmitted through the laid optical fiber, wavelength dispersion will cause transmission degradation to occur. Below, waveform shaping process, which is a means to compensate for dispersion in the access network, and results of the 80km transmissions are described.

1) Dispersion Compensation using Waveform Shaping Process

In the core network, transmission degradation is compensated using dispersion compensation fiber, etc. However, in the access network, the different distances to each user and cost must be considered. Recent advances in electrical processing technology have made it possible to perform signal processing on gigabit signals using DSP. Therefore, a method of compensating for waveform distortion with electrical wave shaping process after the optical/electrical conversion was incorporated.

Figure 3 shows the effect of the waveform shaping process using an equalizer. **Figure 3 (a)** shows the signal waveform after an 80km transmission, and **Figure 3 (b)** shows the waveform subjected to waveform shaping process after an 80km transmission. Waveform in **Figure 3 (a)** shows degradation due to the influence of wavelength dispersion, whereas the waveform in **Figure 3 (b)** has a large eye, which confirms waveform degradation was compensated.



(a) Waveform after an 80 km Transmission (b) Waveform after a Waveform Shaping Process

Figure 3. Waveform Shaping Process using an Equalizer

2) 80km Transmission Experiment

Results of the transmission experiment conducted to show the effectiveness of the developed technology are

*1) Difference between optical launched power of the transmitter and optical sensitivity of the receiver (expressed in dB).

presented below. In order to utilize the benefits of the long reach, future consolidation of OLTs and office integration were assumed and the distance was chosen as 80km.

The experimental setup that assumes a PON system is shown in **Figure 4**. Considering cost, the booster and optical preamplifier using the burst EDFA were only placed on the OLT side. The waveform shaping process (CTLE/DFE) will be incorporated as a DSP in future, and therefore placed after the receiver at both the OLT and ONU sides. A 1575nm wavelength was used in downstream direction and a 1535nm wavelength in the upstream direction. BER, which indicates performance, was measured using the BERT function in the FPGA.

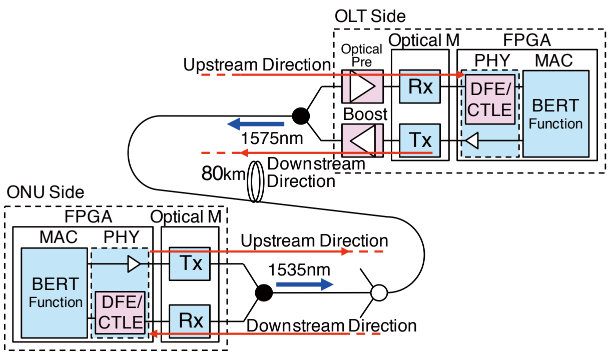
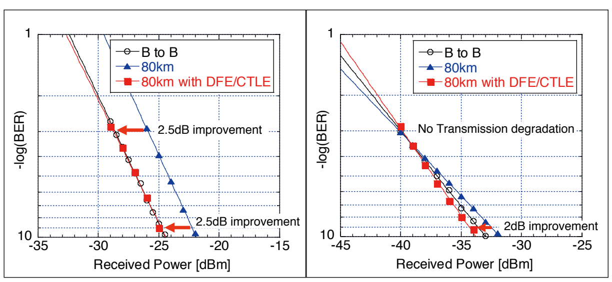


Figure 4. Experimental setup of the PON system



(a) Downstream Direction (b) Upstream Direction

Figure 5. Results of 80km Transmission Experiment

Figure 5 shows the measurement results. **Figure 5 (a)** is the measurement results in the downstream direction, and **Figure 5 (b)** is the upstream direction[4]. ○ are the results of no transmission (back to back), ▲ are the results after the transmission and ■ are the results when waveform shaping process was performed after transmission. The 80km transmission distortion has been compensated in both directions confirming that long reach is possible.

Future Efforts

Image of a virtual network for realizing a high-quality, low-power consumption optical access network, WDM/TDM-PON system regarded as the key technology behind the virtual network, and developmental status of the high functionality transceiver have been presented. In addition to the practical development of a WDM/TDM-PON system, work will commence toward the establishment of a virtual optical access technology in anticipation of accommodating mobile devices. OKI plans to proceed with the development of bandwidth allocation/traffic control technology and sleep control of various devices for optical radio fusion network.

Part of this WDM/TDM-PON R&D initiative was commissioned by Japan's Ministry of Internal Affairs and Communications as part of its "Research and Development Project for the Ultra-high Speed and Green Photonic Networks" program. ◆◆

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TIPS 【Glossary】

SDN: Software-Defined Networking
Technology to centrally control communication devices with software and make dynamic changes

TDM: Time Division Multiplexing

WDM: Wavelength Division Multiplexing

PON: Passive Optical Network
Technology to connect several subscribers using a single optical fiber

DFE: Decision Feedback Equalizer

CTLE: Continuous Time Linear Equalizer

DSP: Digital Signal Processor

FPGA: Field-Programmable Gate Array
Programmable LSI