Development of Asymmetric 10G-EPON System

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Gigabit Ethernet-passive optical network (GE-PON), which was ratified by the Institute of Electrical and Electronics Engineers (IEEE) 802.3 committee in 2004, has been widely used for FTTH service in Asia, particularly in Japan. However, five years have passed since the inauguration of its commercial deployments and Internet service providers are not satisfied with the GE-PON any more for their providing latest broadband applications such as high-definition video distribution. In response to such situation, IEEE802.3 has started to standardize 10G-EPON, whose transmission rate is ten times faster than conventional GE-PON, for the next generation FTTH system. Along with standardization activities for 10G-EPON, the authors have also developed an asymmetric 10G-EPON system and succeeded in demonstrating its technical feasibility.

Keywords: FTTH, 10G-EPON, asymmetric, FEC

1. Introduction

The number of Japanese broadband service subscribers has exceeded 30 million at the end of December, 2008. Particularly the Fiber To The Home (FTTH) service has grown rapidly and got 14 million subscribers, and dominates 48% of the whole broadband service [(1)]. It is expected that the number of the FTTH subscribers will grow continuously in future.

Gigabit Ethernet passive optical network (GE-PON), which is ratified on June 2004 by IEEE802.3, is widely deployed for Japanese FTTH service. However, five years have passed since the inauguration of its commercial deployment. Recently the IP distribution of land-based digital television and the video distribution of multi channel have been provided for the broadband subscribers. By these trends, it is anticipated that the 1 Gb/s bandwidth of GE-PON is not enough to accommodate the future applications. So the next generation FTTH system which has faster speed is strongly expected. In response to such situation, IEEE802.3 has started to standardize 10G-EPON on March 2006. The 10G-EPON is going to be ratified on September 2009. The transmission rate of 10G-EPON is ten times faster than conventional GE-PON. The downstream rate of 10G-EPON is 10 Gb/s, while its upstream rates are 1 Gb/s and 10 Gb/s. The 1 Gb/s upstream system is called asymmetric 10G-EPON, whereas the 10 Gb/s upstream system is called symmetric 10G-EPON. The authors have developed an asymmetric 10G-EPON prototype and eva luated it. In this paper the authors explain the prototype specification and discuss the evaluation results.

2. 10G-EPON Systems

2-1 Requirement of Specification

The FTTH service using GE-PON systems is widely deployed in Japan. Establishing a new optical access network for the 10G-EPON systems from the beginning will require huge amount of investments and time. Therefore, the 10G-EPON systems need to work on existing optical access networks. Smooth replacement of GE-PON with 10G-EPON is also very important. Thus, there are two requirements; 1. 10G-EPON needs to support a maximum channel insertion loss of 29 dB or more and 2. 10G-EPON need to coexist with GE-PON in the same optical access networks.

2-2 Standardization

IEEE802.3av Task Force (TF) is carrying out the standardization of 10G-EPON, considering the above requirements. Draft 3.1 was submitted to TF in March 2009 and technical contents are almost completed. To achieve a 29dB channel insertion loss, two PMD classes were established; PRX30 for asymmetric 10G-EPON and PR30 for symmetric 10G-EPON. **Table 1** shows the specification of PRX30 downstream. To meet the maximum channel insertion loss requirement, three technologies: powerful optical transmitters, sensitive optical receivers and Forward Error Correction (FEC) in electrical digital circuits, are applied. The FEC function is optional for GE-PON systems, while it is mandatory for 10G-EPON systems to achieve the strict requirement. In terms of the 1Gb/s upstream of PRX30, the specification of GE-PON was reflected.

As for the second requirement, wavelength allocation was defined to realize the coexistence with GE-PON. **Figure 1** shows the wavelength allocation of 10G-EPON and

Table 1. PRX30 Downstream Specification

Line rate	10.3125 Gb/s
Wavelength	1575-1580 nm
Average launch power	+2 ~ +5 (dBm)
Extinction ratio	9 dB
Channel loss (max)	29 dB
TDP(max)	1.5 dB
ONU RX sensitivity @BER=10^{-3}	-28.5 dBm

G-EPON. The wavelength division multiplexing (WDM) method was applied in the downstream direction. For 10G-EPON downstream, 1577 nm was assigned. On the other hand, the time division mechanism (TDM) method was adopted in the upstream direction. In the case of asymmetric 10G-EPON systems, both 10G-EPON ONU and GE-PON ONU transmit speed are at 1Gb/s in the upstream direction and the upstream bursts are single rates and multiplexed by the TDM method.

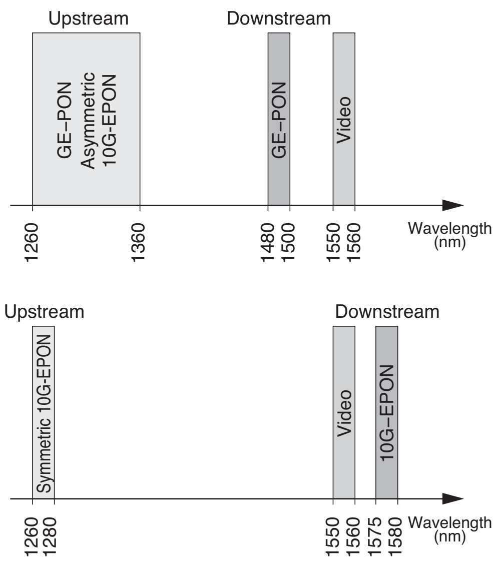


Fig. 1. Wavelength Allocation

3. Prototype of Asymmetric 10G-EPON Systems

3-1 Development Policy

The authors developed the optical interface and digital circuit in prototypes, while taking part in the standardization activity of 10G-EPON. The authors also evaluated the technical feasibility of newly applied technology in the standardization process. A daughter board structure was applied to a passive optical interface for evaluation flexibility. Field programmable gate array (FPGA) was used as PON digital LSI.

Optical components used in optical interfaces contain core technology. Regarding optical devices, the authors have closely cooperated with the research and development division of optical devices in Sumitomo Electric so as to release the prototype earlier.

3-2 Specification of prototype

Table 2 shows OLT and ONU of asymmetric 10G-EPON prototypes, and **Fig. 2** shows their appearance.

Table 2. Specification of Asymmetric 10G-EPON Prototype

PON Interface	PRX30
SNI Interface	10G-BASE-LR, 1000BASE-T
Control Port	RS232C
Power	AC100V 50/60Hz
Power Consumption	60 W (typical)

(a) OLT

PON Interface	PRX30
UNI Interface	1000BASE-T
Management Port	RX232C
Power	AC100V 50/60Hz
Power Consumption	45 W (typical)

(b) ONU

(a) OLT (b) ONU

Fig. 2. Appearance of 10G-EPON Prototype

4. Evaluation

4-1 Maximum Channel Insertion Loss

(10G downstream optical characteristics)

The 1Gb/s upstream is technically feasible by adopting the burst technology of GE-PON systems. Here, the authors describe a maximum channel insertion loss in the 10Gb/s downstream.

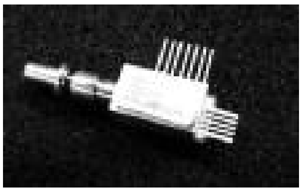
Table 3 shows an example of optical transmit characteristics. **Figure 3** shows the appearance and optical output waveform from an optical transmitter which includes a high power DFB-EA laser.

The authors have confirmed that the optical output characteristic meets the specification of IEEE802.3av's draft. The optical output wave also shows a margin enough for the eye mask definition of PRX30.

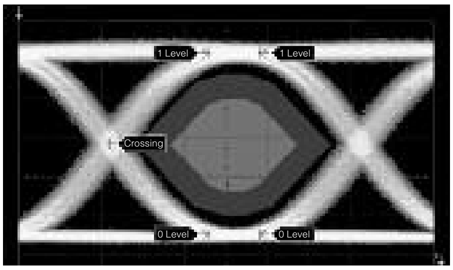
Figure 4 shows the appearance of an ONU bi-directional device. Avalanche photo diode (APD) was adopted as an optical receiver for a higher sensitivity. **Figure 5** shows the degradation of optical eye patterns and a bit error characteristic by using the above transmitter with 20 Km optical fiber. Despite 20 Km transmission, the penalty of optical dispersion is approximately 0.6 dB. The authors

Table 3. Transmission Characteristics of OLT Downstream

Wavelength	1577.6 nm
Extinction ratio	10 dB
Average launch power	4.1 dBm



(a) OLT transmit device



(b) Optical output (with filter)

Fig. 3. OLT Transmit Device and Optical Output

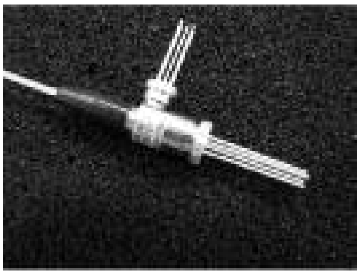
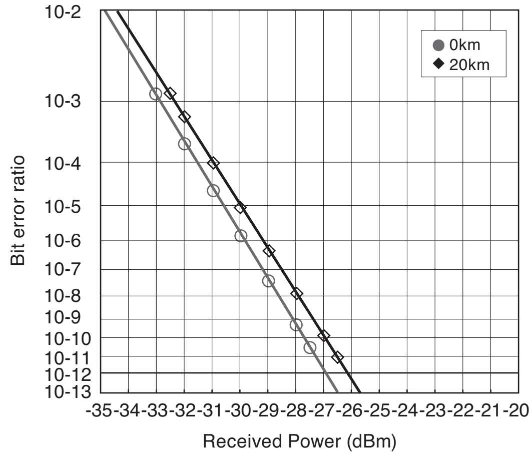


Fig. 4. ONU Bi-directional Device



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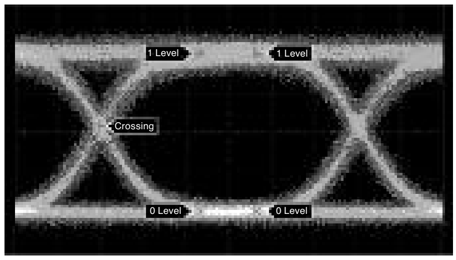

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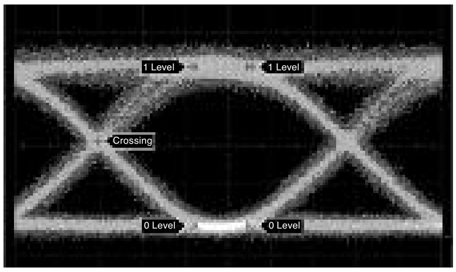

Wavelength 1577.6 nm
Fiber Dispersion 354 ps/nm@20km

Fig. 5. BER Characteristics of 10G Downstream

have confirmed that the specification meets the draft standardization regarding PRX30.

(10G downstream Forward Error Correction (FEC))

The FEC function of GE-PON is optional, while it is mandatory for 10G-EPON to achieve a 29 dB channel insertion loss. Reed Solomon (255, 223) is adopted as FEC algorithm, and 10G-EPON accommodates the FEC parity overhead by the in-band rate method. Accordingly, the overhead is about 13% from MAC layer's point of view, and therefore the maximum throughput of Ethernet frames is approximately 8.7 Gb/s.

Figure 6 shows bit error characteristics with the FEC function. Electrical coding gain of Reed Solomon (255, 223) is about 7.2 dB. The optical coding gain of RS depends on the noise characteristics of an optical receive device. In the case of PIN-PD, the optical coding gain is the half of the electrical coding gain, because thermal noise is dominant in a receiver. Otherwise, in the case of an APD device used for 10G-EPON, thermal and shot noise would be mixed in the receiver. After all, the optical coding gain is about 0.7 – 0.9 times of the electrical coding gain. When the shot noise is more dominate, the optical coding gain is closer to the electrical coding gain. The optical coding gain in **Figure 6** is 6.4 dB, and the receive sensitivity (BER = 10^{-12}) after FEC decoding is -31.7 dBm. The BER is estimated from the packet error rate (PER) of Ethernet frames and is calculated by the following equation (1), N is the bit length of an Ethernet frame.

$$PER=1-(1-BER)^{N} \quad \cdots\cdots\cdots\cdots\cdots\cdots \quad (1)$$

(Power budget)

The optical power of OLT 10G downstream was 4.1dBm, and the receive sensitivity of ONU after FEC decoding was -31.7 dBm. As a result, the 10G downstream power budget was 35.8 dB, which is a sufficient margin compared with the PRX30 downstream power budget requirement of 30.5dB (maximum channel insertion loss 29.0 dB + maximum dispersion penalty 1.5 dB).

4-2 Coexistence with GE-PON

The authors set up practical equipment environment to evaluate the upstream throughput fairness between

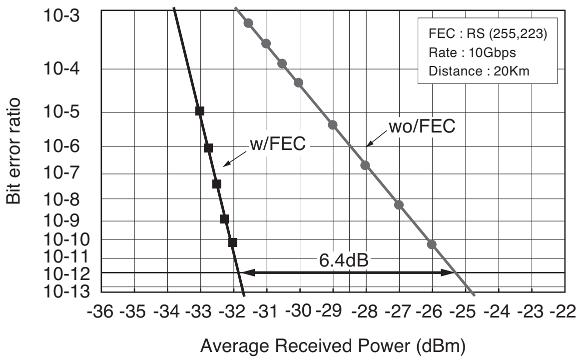

Fig. 6. BER Characteristics after FEC Decode

asynchronous 10G-EPON ONUs (called 10G ONU) and GE-PON ONUs (called 1G ONU). The two kinds of ONUs existed in the same optical fiber. **Figure 7** shows the environment that consists of 16 units of 10G ONU and 16 units of 1G ONU.

Figure 8 shows the result of the output throughput from an OLT SNI port. The input rate into 16 units of 10G ONU was always set to 100% and the input rate into 16 units of 1G ONU was gradually increased from zero. As the traffic into 1G ONU increased, the throughput from 10G ONU decreased. At last the throughput from 10G ONU and 1G ONU became the same. As a result, the authors confirmed the fairness of upstream throughput regardless of ONU types

Figure 9 shows the latency time of downstream data. The authors measured the latency with the combination of two ONU types (10G and 1G) and two OLT SNI port types (10G and 1G).

We have confirmed the following facts from the result.

(1) The frame latency of 10G ONU is shorter than that of 1G ONU.

(2) The latency difference between 10G ONU and 1G ONU depends on a frame size. (maximum time: 30 us)

(3) The PON transmission speed is a dominant parameter rather than OLT SNI speed.

The reason of fact (3) is that SNI speed affects OLT receiving time, while PON link speed affects OLT transmitting time and ONU receiving time.

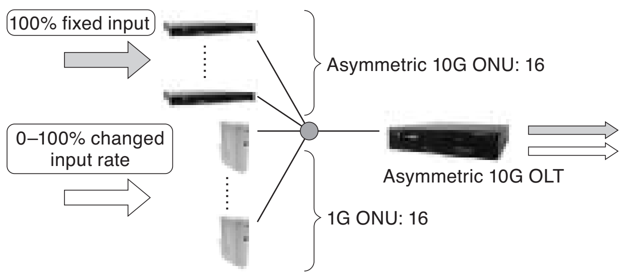

Fig. 7. Evaluation Environment of Co-existence with GE-PON

Meanwhile, in terms of downstream WDM modulation, the authors confirmed the technical feasibility of the coexistence of 10G ONU and 1G ONU in the same optical fiber. The GE-PON ONU employs an optical low-pass filter (LPF) which blocks wavelength over 1550nm. The 10G-EPON ONU employs the optical band-pass filter (BPF) which transmits wavelength between 1575 and 1580 nm.

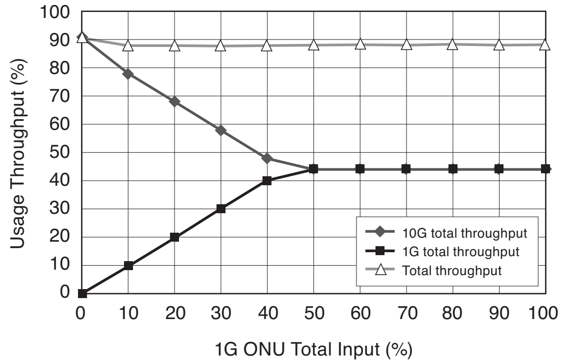

Fig. 8. Upstream Efficiency under Co-existence

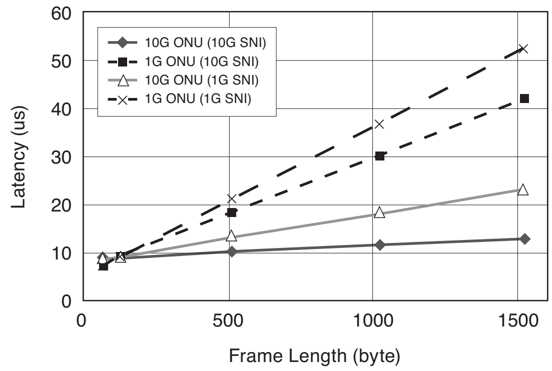

Fig. 9. Latency of Downstream

5. Conclusion

The authors have developed the prototypes of 10G-EPON OLT and ONU which comply with the draft standard of the 10G-EPON and confirmed their technical feasibility with the sufficient margins resulting from the prototype evaluation.

In terms of the coexistence of 10G-EPON and GE-PON, we have confirmed the technical feasibility in the evaluation environment which consists of practical ONU numbers.

The authors will continue to develop the symmetric 10G-EPON of 10Gb/s upstream, aiming at the reduction in the costs and power consumption of each component.

*Ethernet is a trademark of Xerox Corporation.

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