

논문 2006-43TC-2-10

# 이더넷 PON 기술 기반 FTTH 시스템 구현

( Implementation of FTTH System based on Ethernet PON Technology )

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## 요 약

본 논문은 이더넷 PON 기술 기반 FTTH 시스템 구현에 관한 것이다. 이 시스템은 OLT와 ONT로 구성되었다. OLT는 시스템 당 최대 24개의 기가비트 인터페이스를 지원하며, 향후 디지털 통신 방송 융합 서비스를 고려한 설계로 융통성과 확장성을 가지고 있다. OLT 시스템은 스위치 모듈, 가입자 모듈, 프로세서 모듈, 그리고 E-PON 링크 모듈로 이루어져 있으며, 리눅스 운영체제를 탑재하고 있다. ONT는 가입자 댁내에 실장되어 IP-TV 및 인터넷 서비스를 제공할 수 있으며, IP-TV 신호 전달 특성을 개선하기 위하여 IP-TV 전용 인터페이스를 가지고 있다. 우리는 이 시스템을 통하여 E-PON MAC 성능을 측정하였으며, IP-TV용 가상링크와 데이터용 가상링크를 분리하여 ONT에서 트래픽별 QoS 제어 특성을 측정하였다.

## Abstract

This paper addresses the implementation of FTTH system based on Ethernet PON technology. This system consists of OLT and ONT. OLT supports the maximum 24 Gigabit Ethernet interfaces, and then has the flexibility and the scalability for supplying digital communication and broadcasting convergence service in the near future. OLT system consists of switch module, subscriber module, processor module, and E-PON link module, and has the operating system based on Linux. ONT is installed in customer premise to supply both IP-TV and Internet service. Also ONT has the dedicated interface for IP-TV to improve the transmission characteristics of IP-TV signal. We measure the performance of E-PON MAC through this system, and then QoS control characteristics per traffic in ONT by separating the virtual link for IP-TV from that for data.

**Keywords :** E-PON, FTTH, OLT, ONT, TPS

## 1. Introduction

An Internet service has changed from simple Internet search service or information provision service of data transmission type to motion video multimedia one. Such phenomenon has been occurred in diverse fields. Broadband convergence Network (BcN) is aimed at the infrastructure installation to supply communication and broadcasting convergence service and then is installing the infrastructure network and the

subscriber access network. Triple Play Service (TPS) of CATV vendor is also to supply video, data, and voice simultaneously through one broadcasting line and threatens the communication businessmen in the world. As Internet Service Providers (ISPs) have not the proper method to increase the sale volume through the existing Internet connection service, they seek the method actively to increase the sale volume by providing the new service of high value added, such as VoD. Such paradigm changes require the new subscriber access network. The new one of many subscriber access technologies is Fiber To The Home (FTTH). FTTH is the infrastructure configured to

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접수일자 : 2005년12월26일, 수정완료일 : 2006년2월15일

install the optic cable up to subscriber and then supply the diverse services through this network. FTTH is the subscriber network architecture that can supply the multimedia services requiring high QoS and bandwidth guarantee. As technologies, such as xDSL (Digital Subscriber Line), Cable Network, and LAN, use the method to share the bandwidth, those is the optimum solution that can supply QoS suitable for Internet search. But those technologies are not suitable for services that must guarantee QoS and bandwidth absolutely, such as video and voice services based on IP.

Therefore, the new technology is required to provide subscribers with the diverse real-time multimedia services using one network. This must be low-cost, simple, and scalable technology. E-PON (Ethernet Passive Optical Network) technology, that combines low-cost Ethernet technology and optical fiber infrastructure, has been appeared as solution of next generation access network. The transmission speed of E-PON is 1 Gbps and symmetric in bidirectional. It is possible to save the cost through simple network architecture, efficient operation, and low maintenance cost of optical IP Ethernet network. E-PON uses point-to-multipoint one instead of point-to-point topology, and does not use the active components, such as repeater, amplifier, and laser. And E-PON can overcome the shortcoming of point-to-point optical solution by reducing the number of laser required in central office.

This paper addresses the implementation of FTTH system based on Ethernet PON technology. This system consists of OLT and ONT. OLT supports the maximum 24 Gigabit Ethernet interfaces, and then has the flexibility and the scalability for supplying digital communication and broadcasting convergence service in the near future. ONT has the dedicated interface for IP-TV to improve the transmission characteristics of IP-TV signal. We measure the performance of E-PON MAC through this system, and then QoS control characteristics per traffic in ONT by separating the virtual link for IP-TV from that for data.

In this paper, chapter 2 addresses E-PON archi-

tecture and services, chapter 3 includes the implementation of E-PON system, such as OLT system and ONT module. Chapter 4 addresses QoS function and system performance of E-PON system and chapter 5 includes conclusion.

## 2. E-PON architecture

Figure 1 shows the configuration of access network consisting of E-PON system. E-PON consists of OLT (Optical Line Terminal), Passive Optical Splitter/Coupler, and many ONTs (Optical Networking Terminals). Because of its simple architecture, the access network can be configured efficiently. As E-PON uses the optic fiber that provides high bandwidth, it is efficient in transmitting data, video, and voice traffic. One optic fiber connected to OLT is branched to many optic fibers (16~64 branches) by Passive Optical Splitter/Coupler, and ONU or ONT are connected to the end of branched optic fiber.

Table 1 shows the services that E-PON can support. TDM service can be supported through TDM service module of E-PON system. These services are LL (Leased Line) service and POTS service.

OLT and ONU/ONT are located at both end point of optical splitter, and they both are connected to optical splitter through optic fiber. E-PON system concentrates many signals into one signal or distributes one signal to many signals through optical splitter based on the transmission direction of optical signal. As OLT and ONUs/ONTs are connected in point-to-multipoint type,

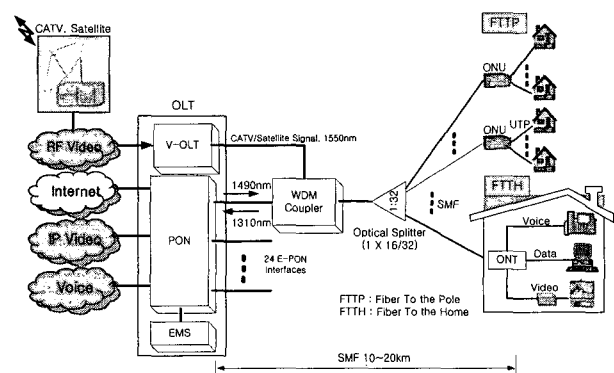


그림 1. E-PON 네트워크 구성도.

Fig. 1. E-PON network configuration

표 1. E-PON 시스템의 서비스  
Table 1. Services of E-PON system.

Category	Service	Contents
Telephony	Video phone	-Interworking with IP premium network -2Mbps/call -End-to-end delay time: 80ms -Jitter: 30ms -Loss ratio: 10-3
Video	IP-TV	-CDN interworking -Video (multicast) on the level of HDTV
	VoD/EoD	-VoD on the level of HDTV (20Mbps) -EoD on the level of SDTV (6Mbps)
	RF (Option)	-CATV and Satellite broadcasting
Data	Web/interactive game	-Interworking with services -IEEE802.3 Ethernet
TDM (Option)	LL/POTS	-E1 for FTTB and FTTC subscribers -POTS for FTTH

the installation cost of optic fiber is chapter than one of point-to-point type.

E-PON consists of OLT, optical splitter, and many ONUs/ONTs, and is configured in efficient method because of the simple architecture. As E-PON uses the optic fiber of high bandwidth, it is efficient to transmit data, video, and voice traffic. The data stream of E-PON system consists of upstream and downstream data as shown in figure 2.

IEEE802.3 standard defines two basic configurations of Ethernet network. One is the method that be configured on shared medium using CSMA/CD protocol, another is the one that stations can be connected to using switch using full duplex point-to-point link. E-PON is the combination of above two methods. In downstream, the frame transmitted by OLT is delivered to ONT through passive splitter. OLT broadcasts a packet to multiple ONTs, and then the destination ONT extracts the packet based on MAC address. In upstream, because of the direction in splitter, a data frame from any ONT is arrived at OLT and not ONT. Therefore the operation of E-PON is

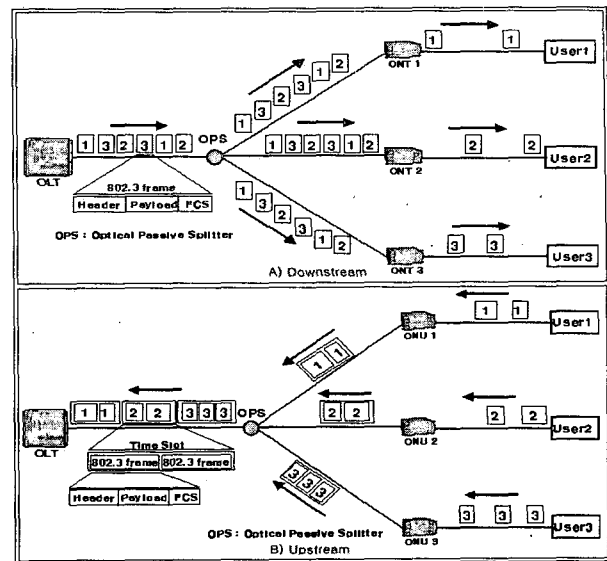


그림 2. E-PON에서 트래픽 흐름  
Fig. 2. Traffic flow in E-PON.

similar to point-to-point architecture. But contrary to strict point-to-point, the data frames from different ONTs in E-PON can be conflicted. So in upstream, ONTs must have the arbitration mechanism to avert the collision and share the optic channel capacity fairly. Figure 2 shows the time-shared data flow of upstream in E-PON. In this figure, all ONTs synchronize the common standard time, and then the time slot is assigned to each ONT. Each time slot can delivery many Ethernet frames. ONT will buffer the frames received from subscribers until its own time slot is arrived at. When its own frame is arrived at, the ONT bursts all frames at full channel speed. When there are no frames in buffer to fill the entire time slots, the ONT transmits 10bits idle characteristics. There are static assigning method (TDMA) and dynamic adaptive method based on the instantaneous queue length of all ONTs (statistics multiplexing) in time slot assigning methods.

### 3. The implementation of E-PON system

Subscriber interface of ultra high-speed optical subscriber network consists of ONU/ONT, splitter, and E-PON, that subscriber connects to Internet through OLT as shown in figure 3. E-PON shelf supports the

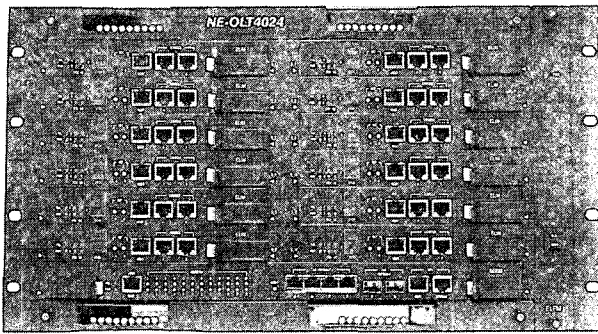


그림 3. E-PON 시스템 구성도

Fig. 3. E-PON system configuration.

standard that can accommodate both broadcasting and data service. This shelf can accommodate up to 12 line cards, and each card can support 2 optic ports of AFC type. Therefore this shelf can support maximum 24 optic ports, and then each port can accommodate up to 32 ONTs. Main switch and controller card in this shelf supports maximum 4 1000Base-Tx ports and two 1000Base-Fx ports of APC type for uplink.

E-PON shelf performs OLT operation, and terminating function for ONU or ONT. GESM (Gigabit Ethernet Switching Module) card performs uplink and control function. It has 1000Base-Tx and 1000Base-Fx interfaces for uplink. And it supports link aggregation function to supply the function for increasing bandwidth. GESM card includes Gigabit Ethernet switch that supports L2/L3 switching function for 28 ports. It has 4 Gigabit Ethernet ports for uplink port, and all 4 ports can be used for 1000Base-Tx. For Fx interface, this card needs a separate Fx interface. So this card has the configuration that two of four Tx ports can be used for Fx interface instead.

ELIM card supports two E-PON interfaces, and is connected to GESM card using 1000Base-Tx signal in backplane. Processor built-in in E-PON chip of ELIM card is assigned to the private IP address for the appropriate slot location, and communicates with main processor in UDP message. And processor built-in in E-PON chip is connected to main processor through 100Mbps Ethernet interface for management, and then exchanges the control message with that processor.

ELIM card supports the control path for control and

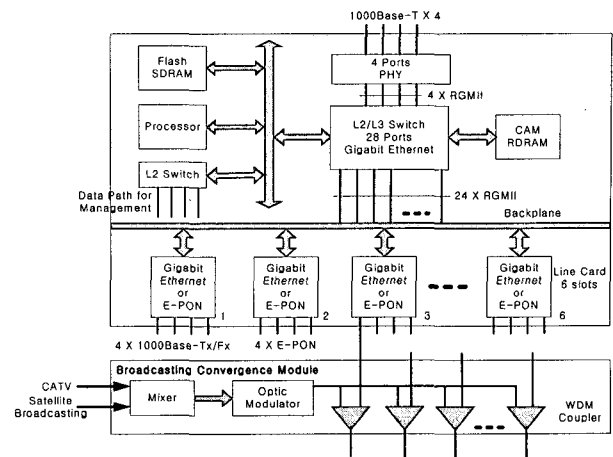


그림 4. OLT 시스템 블록도

Fig. 4. OLT system block diagram.

표 2. ELIM 카드 기능

Table 2. ELIM card function.

Function	Remark
MAC bridging function between Ethernet Port and E-PON port	Supports 4K MAC address table
Supports up to 256 LLIDs	Supports VLAN mapping per LLID
DBA (Dynamic Bandwidth Allocation) function based on hardware	
Automatic perception and link setting function for ONT	
Set up SLA function for virtual link configured with ONT	Bandwidth, delay characteristics
Set up classification, filtering and monitoring function for ONT	
Setup VLAN mode and IEEE802.1p Cos mapping function for OLT	
Function gathering traffic statistics per OLT port, per ONT, and per LLID	Static MAC setting, MAC learning monitoring, MAC address limitation function
MAC management function per ONT and per LLID	
Management function for OLT, ONT	Enable/disable function

statue/statistics information monitoring of all ONTs connected to link. Each E-PON chip provides RS-232C interface for parameter setting and status monitoring. And this card supports 100Mbps Ethernet port for local management to test card itself. Main functions of ELIM cars are shown in table 2.

ONT board has all functions defined in IEEE802.3ah standard through E-PON MAC chip. This board operates as multi-port bridge between IEEE802.3ah E-PON MAC and two 10/100Base-T MACs. Each 10/100Base-T MAC has unique LLID based on its own MAC address. Each ONT port appears as separate point-to-point link through E-PON emulation layer in ELIM (OLT). E-PON MAC chip of ELIM card also supports DBA, traffic shaping, QoS, VLAN tagging, and encapsulation function. ONT is subscriber equipment of E-PON network (CPE: Customer Premise Device), and ONT converts the incoming optical PON traffics into phone, T1/E1, and 10/100Mbps Ethernet service for end user. The main functions of ONT are shown in table 3.

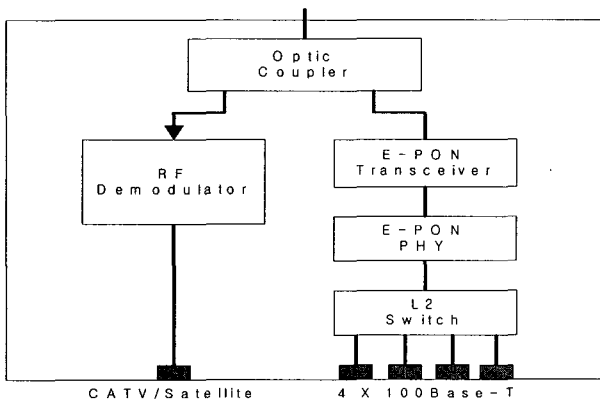


그림 5. ONT 구성도  
Fig. 5. ONT configuration.

표 3. ONT 보드 기능  
Table 3. ONT board function.

Function	Remark
MAC bridging function between E-PON and Ethernet	64 MAC addresses learning for IP-TV and data port
MAC management function	
Set up independent virtual link to IP-TV dedicated port and data port	Video service is separated from Internet data
Set up the priority queues of four levels using 128kbytes buffer to support QoS	Supports classification and filtering function by L2/L3/L4
Supports queue assigning function by IP ToS or IEEE802.1p CoS	

#### 4. The performance of E-PON system

To supports IP-TV service for broadcasting and VoD service based on IP, voice transmission service based on VoIP, and Internet service simultaneously in home, we use the technologies that OLT and ONT can be configured in optimum. First, ONT has the dedicated port for IP-TV and the data one for VoIP/Internet. Second, IP-TV traffic can be separated from data one to prevent deteriorating the quality of IP-TV by installing the separated virtual link for IP-TV port and data one between OLT and ONT. Third, for the traffics on data port, we assign four priority queues to transmit VoIP traffic and stream one based on data preferentially, and then perform the priority queuing for them by ToS/IEEE802.1p. Therefore, we also can assign the link suitable for triple play services through technologies showed in figure 9.

The traffic is processed in OLT to support QoS. In OLT, VLAN having the virtual link for data is separated from VLAN having the virtual one for IP-TV, and then VLAN attribute is set up according to traffic characteristics. OLT can transmit the video traffic preferentially by assigning highest priority to VLAN having link for IP-TV sensitive to delay. In VLAN having the traffic for data, OLT can perform priority scheduling of four steps by performing classification according to traffics (to guarantee transmitting VoIP traffic preferentially).

Figure 10 shows the location of congestion generation in the existing E-PON system. Therefore,

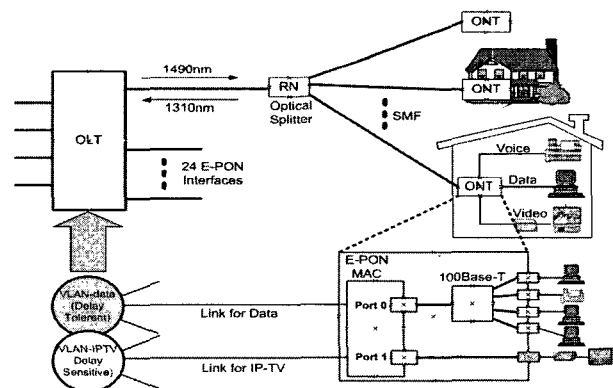


그림 9. Triple Play Service를 위한 링크 할당  
Fig. 9. Link assignment for Triple play service.

QoS control technologies between OLT and ONT can improve the quality characteristics of traffics sensitive to delay and loss by preventing or dealing with the congestion generation deteriorating the quality of downstream traffic.

The problems of existing E-PON system and its solutions are following: When the traffics received from multiple uplinks are concentrated on the specific E-PON port, it can deteriorate the traffic quality by momentary congestion. In this case, there is no method to prevent the congestion ultimately, but the function is required that can delivery the traffics sensitive to delay and loss preferentially by the priority queuing or/and scheduling. When a packet is dropped by the congestion, the function is required that have RED applied.

In case of having the customer connection port of 100Mbps, the downstream traffics are concentrated on ONT. So it can deteriorate the characteristics of traffic quality. In this case, if a shaping function is not supported per virtual link in OLT MAC, the possibility that can deteriorate the traffic quality by the momentary congestion is very high. Therefore, ONT must be configured to delivery the traffics sensitive to delay and loss preferentially by priority queuing or/and scheduling function.

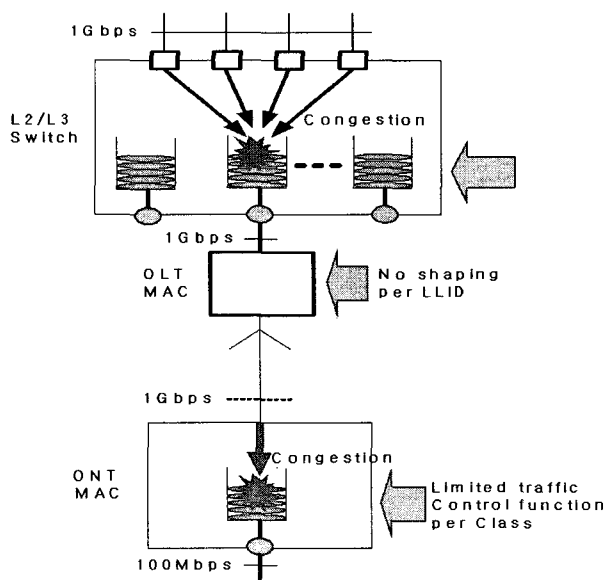


그림 10. 기존 E-PON에서의 폭주 발생 위치  
Fig. 10. The location of congestion in existing E-PON.

And the more elaborate traffic control technologies are required to support triple play service. If a shaping function is supported per virtual link in OLT MAC, a possibility that congestion in ONT can be generated will decrease. If a separate virtual link is applied to for video service, it is advantageous for the guarantee of traffic quality and the billing according to the amount used.

QoS control technologies are applied to OLT and ONT to solve same problems as figure 10. For the traffics received from service network, QoS control technology is applied to that can maintain the quality characteristics required in end-to-end. So it performs the proper QoS control at each congestion point that can be generated during passing through OLT, RN and ONT. Figure 11 shows QoS control functions in OLT and ONT to solve the problems in figure 10.

First, The independent VLANs are set up for both data and IP-TV. Therefore, separating and then treating the traffic having different quality requirements can support the more upgraded QoS control. Second, the different priority control can be done according to different data traffics by applying IEEE802.1p CoS in OLT. Third, the characteristics of traffic jitter and the utilization of network resource can be upgraded by applying RED in congestion. Fourth, Also for virtual link for downstream traffic, the interference by traffics on same path through MAC chip having a bandwidth setup and a shaping function

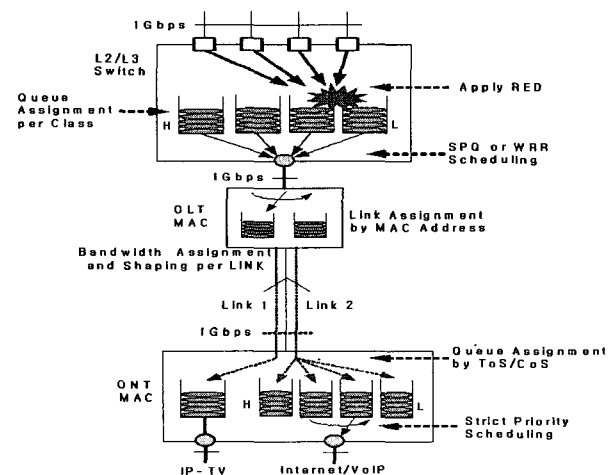


그림 11. OLT/ONT에서 QoS 제어 기능  
Fig. 11. QoS control function in OLT and ONT.

can be minimized. Fifth, by separating the virtual link for IP-TV from the virtual link for data, QoS control characteristics per traffic can be upgraded. Sixth, by applying the queuing and the scheduling function through ToS and CoS in ONT, the transmission quality of traffics sensitive to delay can be maintained.

Figure 12 shows E-PON system configuration for test, the test will be performed for QoS function and system performance. We measure the performance of E-PON MAC through this configuration, and then QoS control characteristics per traffic in ONT by separating the virtual link for IP-TV from that for data.

To measure the performance of E-PON MAC, the test network is configured as shown in figure 13. In this configuration, one E-PON interface is connected to ten ONTs, and then the maximum traffic transmission bandwidth of bi-directional is measured. In this test environment, Ten ONTs are connected to one E-PON

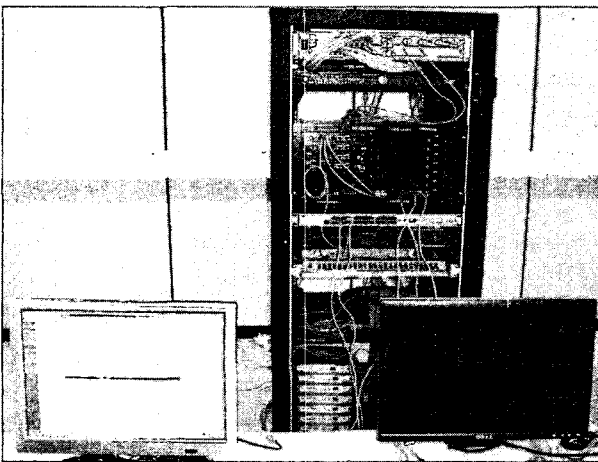


그림 12. 시험을 위한 E-PON 시스템 구성도  
Fig. 12. E-PON system configuration for test.

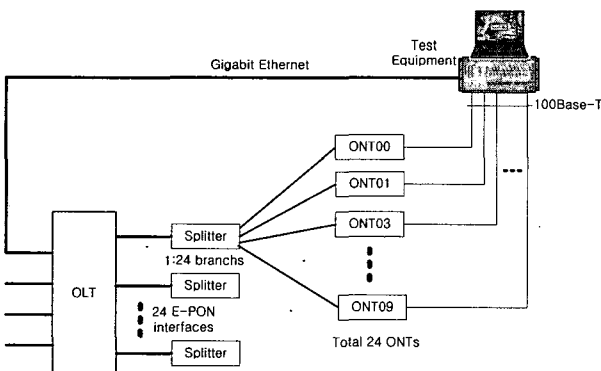


그림 13. 성능 시험을 위한 망 구성도  
Fig. 13. Network configuration for performance test.

interface. Optical splitter has 24 branches, and SMF of 5m lengths is used as optical line. And we set up the traffic parameters for virtual link between OLT and ONT: Maximum allowed bandwidth is 100Mbps, Maximum guaranteed bandwidth is 100Mbps, and Maximum burst size is 10kbyte. We measure the traffic transmission performance for bi-directional through this test environment.

In downstream performance, Gigabit Ethernet port generates 100Mbps traffic to each ONT, and then Ethernet frame received in ONT is counted. We can

Parameter	Parameter set A	Parameter set B
SchedulerMin-Tokens	2 Kbyte	4 Kbyte
Scheduler Max-Tokens	2 Kbyte	4 Kbyte

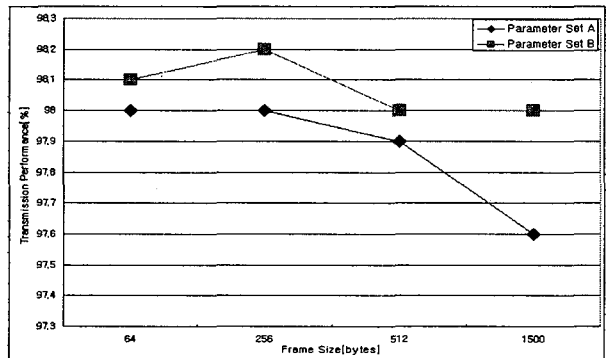


그림 14. downstream에서 시험 결과  
Fig. 14. Test result for downstream.

Parameter	Parameter set A	Parameter set B	Parameter set C
DBA tokens	4 Kbyte	8 Kbyte	10 Kbyte
Scheduler Min-Tokens	2 Kbyte	4 Kbyte	6 Kbyte
Scheduler Max-Tokens	2 Kbyte	4 Kbyte	6 Kbyte

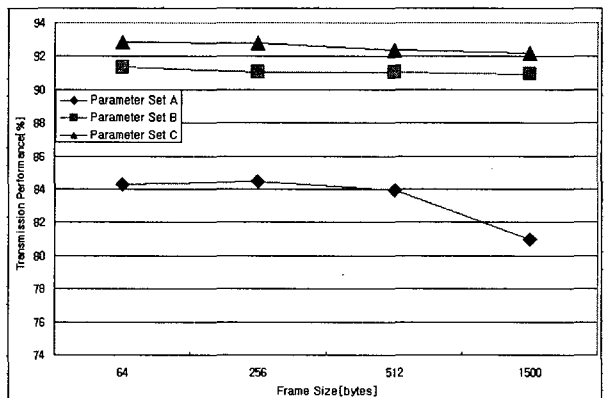


그림 15. upstream에서 시험 결과  
Fig. 15. Test result for upstream.

표 4. QoS 테스트를 위한 시나리오

Table 4. the scenario for QoS test.

	Conn. 1		Conn. 2		Broadcasting		Load [%]
	BE	QoS	BE	QoS	BE	QoS	
Bandwidth	20[%]		30[%]		20[%]		70
Tx[Mbps]	159.18	159.18	238.78	238.78	159.18	159.18	
Rx[Mbps]	159.18	159.18	238.78	238.78	159.18	159.18	
Bandwidth	50[%]		30[%]		20[%]		100
Tx[Mbps]	390	159.18	238.78	238.78	159.18	159.18	
Rx[Mbps]	390	159.18	238.78	238.78	159.18	159.18	
Bandwidth	80[%]		30[%]		20[%]		130
Tx[Mbps]	636.73	636.73	238.78	238.78	159.18	159.18	
Rx[Mbps]	430.04	445.61	161.27	147.07	107.5	159.18	
Bandwidth	80[%]		60[%]		20[%]		160
Tx[Mbps]	636.73	636.73	477.55	477.55	159.18	159.18	
Rx[Mbps]	349.42	320.83	262.07	271.86	87.36	159.18	
Bandwidth	95[%]		75[%]		20[%]		190
Tx[Mbps]	756.12	756.12	596.94	596.94	159.18	159.18	
Rx[Mbps]	349.14	324.88	275.86	276.69	73.56	159.18	

verify the performance variation according to the parameter values of downstream scheduler in OLT. Figure 14 show that the performance downstream traffic is closed to line speed.

In upstream performance, 100Mbps traffic is generated to each ONT, and then Ethernet frame received in Gigabit Ethernet port of OLT is counted. We also verify the performance variation according to the parameter values of upstream scheduler in OLT.

Figure 15 shows that the transmission performance in upstream is 81%~92% according to the parameter values.

Table 4 shows the scenario to test QoS control function applied to OLT and ONT. This scenario is applied to the configuration that consists of two links for Internet connection and one link for broadcasting. BE (Best Effort) service or QoS control function is applied to each link, and then we measure the packet loss ration and the delay time for each link. We increase the total load from 70% to 190% in 30% unit. And the total loads are distributed to three links, and the link for broadcasting has the fixed 20 % of total loads because of the guarantee of bandwidth.

Figure 16 shows the delay characteristics for each link measured according to the test scenario. This figure shows the bandwidth guarantee in even congestion state if QoS control function is applied to link for broadcasting. Otherwise, if QoS control function is not applied to link for broadcasting, it shows deteriorating the delay characteristics seriously.

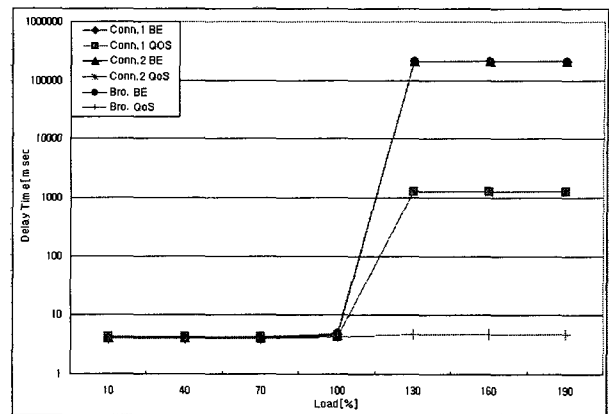


그림 16. E-PON 시스템의 지연 특성

Fig. 16. Delay characteristics in E-PON system.

And if QoS control function is not applied to two links for Internet connection. It also shows deteriorating the delay characteristics seriously. But if QoS control function is applied to those links, the delay characteristics are improved as far as it goes but is not guaranteed certainly like the link for broadcasting.

Figure 17 is packet loss measured according to the test scenario of table 4. In the case of applying QoS control function to the link for broadcasting, this figure shows that the bandwidth is guaranteed and then there is no packet loss in congestion status. But in the case of applying BE (Best Effort) service to the link for broadcasting, this figure shows that the characteristic of packet loss is weakened seriously. Therefore this figure shows that the link for broadcasting sensitive to packet loss must have the guaranteed bandwidth. In this figure, until the load of system reaches 100%, there are no packet losses in all three links, which have BE service or QoS control function. But if system load pass over 100%, there are packet losses in all links except of the link for broadcasting having QoS control function.

The integrated service technology to converge communication and broadcasting in FTTH networks provides communication and broadcasting convergence services through a single fiber by multiplexing data communication signals and broadcasting signals (satellite and CATV) on the light signal level. The subscriber can have a simplified access method of only one optical fiber through the integration of the services

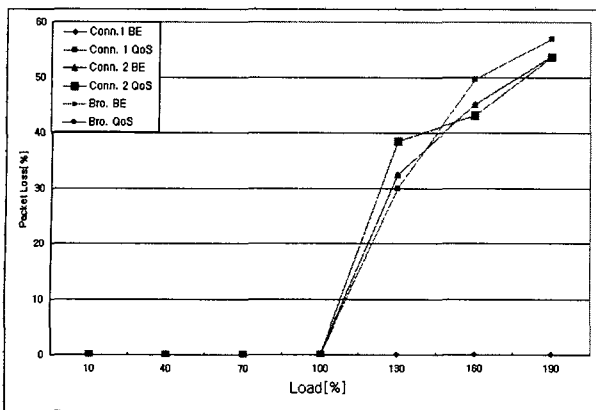


그림 17. E-PON 시스템의 패킷 손실

Fig. 17. Packet loss of E-PON system.

each of which has currently its own separate access network.

This convergence technology in FTTH networks consists of an optical RF transmit module to transform the broadcasting signal to the optical signal, a link distribution module to transmit the optical signal, and an optical RF receive module to transform the optical signal to the broadcasting signal. These technologies make the subscriber network simple, and no major access module or device change is required. These will be used to build a single network having all Internet service network and the broadcasting network, and then provide satellite and CATV broadcasting simultaneously through the public sharing in the MDUs, such as apartment complexes. And These can also provide FTTH-type convergence of communications and broadcasting using PON distribution network, and FTTH-type convergence of communications and broadcasting in non-apartment residential area.

## 5. Conclusion

This paper addresses the implementation of FTTH system based on Ethernet technology. This system consists of OLT and ONT. OLT supports maximum 24 Gigabit Ethernet E-PON interfaces per OLT system, and has two OLT systems per shelf. In near future, this system has flexibility and scalability for communication and broadcasting convergence services,

and then can provide operation and maintenance, system technology.

For this, OLT system consists of switch module, subscriber module, processor module, and E-PON link module. We install Linux operating system in OLT system that includes API performing Layer 2 and Layer3 switching function, so these functions can be used for commercial layer2 and layer3 system, and can accommodate diverse supplementary services that multicasting function and switch chip based on Linux provides. And by connecting multiple ONTs to one OLT, this system can provide cheaper services than other technologies that provide the service of similar quality. ONT is installed in customer premise, and then can provide IP-TV and Internet service, and has the interface of dedicated IP-TV to modify the transmission characteristics of IP-TV signal. In home, the most suitable technologies are used in OLT and ONT to support IP-TV for broadcasting and VoD services based on IP, voice service based on VoIP, and Internet service simultaneously. And by performing the proper QoS control in each domain, which can occur the congestion between OLT and ONT, this system can maintain the requested characteristics of quality between end users.

In near future, we will complete the FTTH system that can provide triple play services by adding TDMoIP (Time Division Multiplexing over IP) function to this system.

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