Optical Access Transport System —GE-PON Platform—

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(Manuscript received March 6, 2009)

In Japan, the number of fiber-to-the-home (FTTH) users surpassed the number of digital subscriber line (DSL) users in 2008. Half of all broadband users are now FTTH users, and the service menu for FTTH is growing. This achievement is attributed to lower service rates as related technologies progress and to services that approach an appropriate level of satisfaction for the user. Fujitsu is proposing the use of the Gigabit Ethernet passive optical network (GE-PON) system, which is applicable to mass production, as an access platform to support this dramatic growth in FTTH users. This paper describes the functions of two key GE-PON products—the optical line terminal (OLT) and optical network unit (ONU)—and those of their supervision and control system. It also touches upon 10G-EPON, a next-generation technology now being standardized at IEEE. Fujitsu intends to develop hardware technology to achieve a smooth transition from the existing GE-PON system to 10G-EPON and to provide an access transport system that enables users to enjoy safe and pleasant services in a stress-free way.

1. Introduction

In Japan, the number of broadband service contracts reached 30.11 million as of the end of December 2008. Among these, the number of fiber-to-the-home (FTTH) users was 14.42 million, followed by 11.59 million for digital subscriber line (DSL) and 4.08 million for cable television (CATV). The number of service contracts for FTTH access services now exceeds that of DSL and half of all broadband users are FTTH users. Statistical data on broadband access in Japan[1] from the Ministry of Internal Affairs and Communications (MIC) is shown in **Figure 1**.

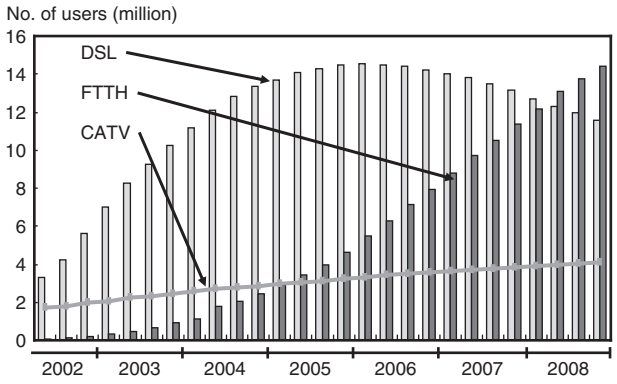
The Ethernet passive optical network (EPON) system, which was standardized in 2004 as IEEE 802.3ah (1-Gb/s bidirectional transmission of Ethernet signals), has come to be widely known in Japan as the Gigabit Ethernet passive optical network (GE-PON), and in this paper, we will refer to it as such. The GE-PON system has been playing a leading role in the rapid expansion of FTTH and has been instrumental in increasing the number of FTTH users to about 14 million over these last five years.

In this paper, we provide some background to the diffusion of FTTH services—the root of the optical access system—and focus on the GE-PON platform supporting those services. We describe the latest GE-PON technologies and discuss future technology trends.

2. FTTH services

The access network has the role of connecting end users with the Internet protocol (IP) core network and supporting a large volume of incoming and outgoing traffic and a wide variety of services. It is expected to provide a high-speed, broadband user environment that is stress-free and safe and secure.

The conversion of the access network to



Source: MIC Press Release: "Number of Broadband Service Contracts, Etc. (as of the end of December 2008)."

Figure 1
Trends in broadband access in Japan.

optical fiber, and FTTH in particular, is highly suitable for this scenario. The FTTH scheme has diffused widely throughout Japan as a driver of broadband services for a variety of reasons. These include advances in optical-fiber laying and installation technologies; reductions in the cost of optical modules (whose total cost is the sum of the costs of optical device processes, assembly technologies, transmit/receive application specific integrated circuits, etc.), which account for most of the equipment cost; reductions in the cost of main circuits due to conversion to large-scale integrated circuits; and lower FTTH service rates that are attractive to users. These changes have led to the provision of inexpensive triple-play and even quadruple-play services (the integration of video-delivery, telephone, Internet access, and wireless services) that can be seen as pioneers of "killer services" that exploit the high-speed, broadband performance, and high-quality features characteristic of optical services.

In this regard, there are high expectations for services that achieve higher quality and more enhanced real-time characteristics by utilizing more bandwidth, such as optical telephony (high-quality IP phones), on-demand TV, video-based online games, and user-generated services.

Moreover, FTTH is expected to become an access platform that can provide end users with smooth access to services that require a guaranteed quality of service and that facilitate fixed-mobile convergence. In short, FTTH is the means of achieving a wide array of services in an integrated manner.

3. GE-PON system

The GE-PON system is a broadband access system standardized by IEEE as an economical solution to achieving high-speed, broadband operation in the first mile of the FTTH access network.[2] An example of a network configuration using GE-PON is shown in **Figure 2**.

This system features an optical line terminal (OLT) and optical network units (ONUs) as subscriber-line terminating equipment. The OLT can accommodate multiple ONUs that connect to optical fibers branching out from couplers. This scheme achieves more efficient use of optical fiber and more effective use of space in the carrier's central office. In addition to providing access to houses, the broadband characteristics of GE-PON can also be used to provide FTTH access to apartment buildings accommodating multiple users, with the last segment from the ONU to individual apartments being via the very-high-speed digital subscriber line system, and to provide an infrastructure for corporate-oriented virtual private network services.

4. OLT

The GE-PON OLT is a line concentrator installed in the carrier's central office. It consists of a 19-inch rack mount chassis that can hold one control/supervision card and 16 line cards in a high-density configuration. An external view of the OLT is shown in **Figure 3 (a)** and the main specifications are given in **Table 1 (a)**. Key features are listed below.

- OLT functions conforming to IEEE 802.3ah specifications
- Bridge functions specified by IEEE 802.1D
- Virtual local area network functions specified by IEEE 802.1Q

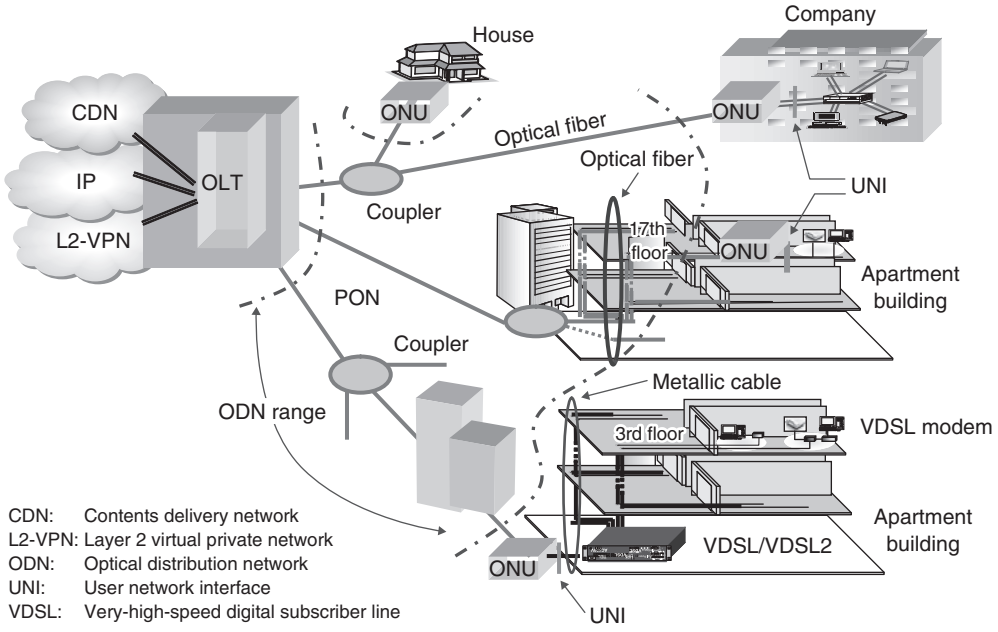


Figure 2
GE-PON network.

- ONU authentication functions and ONU media access control (MAC) address filtering support
- Encryption/decryption functions for the user data frame in the PON interval (encryption algorithm: AES-128, one of the family of advanced encryption algorithms)
- Fair and effective use of bandwidth through dynamic bandwidth allocation (DBA) and a highly extendible method of implementation enabling future enhancements
- Logical link loop-back function and communication recognition between OLT and ONU
- Error counting using test frames and functions enabling measurement of round-trip delay time, performance, and quality
- Remote supervision and control, maintenance functions and fault-troubleshooting functions, and easy-to-use maintenance functions

5. ONU

The GE-PON ONU is installed in the end-user's residence to receive FTTH services or in the machine room or other location in an apartment building. On the upstream side, the ONU takes data received from the end-user's user network interface (UNI) and forwards it to the PON interface; on the downstream side, it takes only data from the central office addressed to itself and forwards it to the UNI side. An external view of the ONU unit is shown in **Figure 3 (b)** and the main specifications are given in **Table 1 (b)**. Key features are listed below.

(a) GE-PON OLT (b) GE-PON ONU

Figure 3
GE-PON system.

Table 1
GE-PON equipment specifications.

(a) OLT

Item		Specifications
Interface	PON interface port	1000Base-PX20-D (power budget: 29 dB)
		Max. 16 lines per OLT
	Trunk interface port	1000Base-T/1000Base-SX/LX (GBIC)
		Max. 16 lines per OLT
	Authentication interface port	10Base-T: 1 line per OLT
	Maintenance interface port	10Base-T: 1 line per OLT
	Equipment-setting interface port	Serial port: 1 line per OLT
Equipment functions		Bridge function, VLAN functions, ONU authentication function, encryption/decryption function, dynamic bandwidth allocation
Redundant configuration		Power supply redundancy, fan redundancy
Maintenance and operation functions		SNMP agent function, loop-back test, ONU power-off detection function, subscriber link status notification
Dimensions		4U size: 432 mm (W) × 350 mm (D) × 174 mm (H)
Weight		20 kg
Installation conditions		EIA-310-D compliant 19-inch rack
Operating environment		Temperature: 0–40°C Humidity: 30–80% R.H. (no condensation)
Power supply, power consumption		AC100 V, DC-48 V, max. 400 W
Electromagnetic interference		VCCI class A compliant

(b) ONU

Item		Specifications
Interface	PON interface port	1 line (1000Base-PX20-U equivalent: 1 line)
	Terminal interface port	2 lines 10/100/1000Base-T: 1 line 10/100Base-TX: 1 line
Equipment functions		Priority control, ONU management system, encryption/decryption function, IGMP snooping function
Redundant configuration		None
Maintenance and operation functions		Loop test
		ONU power-off detection function, subscriber link status notification
Dimensions		156 mm (W) × 33 mm (D) × 163 mm (H)
Weight		About 500 g (excluding power-supply adapter)
Installation conditions		Desktop, wall mounting
Operating environment		Temperature: 0–40°C Humidity: 30–80% R.H. (no condensation)
Power supply, power consumption		AC100 V (50/60 Hz), max. 8 W
Electromagnetic interference		VCCI class B compliant

GBIC: Gigabit interface converter
IGMP: Internet group management protocol
SNMP: Simple network management protocol
VCCI: Voluntary Control Council for Interference by Information Technology Equipment
VLAN: Virtual local area network

- ONU functions conforming to IEEE 802.3ah specifications
- Transmission distance of 20 km; 32 branches
- UNI port up to 1 Gb/s
- Flexible priority control by eight classes of priority queues
- Original ONU management system
- Encryption/decryption in AES-128 mode
- Internet group management protocol (IGMP) snooping function and IP multicasts
- Line-open verification and fault troubleshooting by a logical link loop-back function
- OLT notification of alarms (power off) and UNI status
- Easy monitoring of equipment status provided by light emitting diodes
- Compact configuration. Dimensions: 156 mm (W) × 33 mm (D) × 163 mm (H), weight: about 500 g
- Desktop installation or wall mounting

6. Supervision and control system

The main functions and features of the GE-PON supervision and control system (called the operations system [OpS]) are listed below.

- Supervision and control software running on a UNIX-server/Solaris
- Remote supervision and control of OLT/ONU status and communications on the PON interval through the use of a client/server configuration
- System supervision and control from multiple human-machine interface (HMI) terminals located outside the OpS installation office
- User-friendly graphical user interface and a command line interface for easy maintenance
- Supervision and control of up to 250 OLTs and possible extension to a larger-scale system
- Backups of the OpS itself and of configuration information about the OLTs being supervised and rapid restoration in the event of a system failure
- Structure conducive to program updates and future function extensions

These functions and features enable the construction of a flexible supervision and control system.

7. 10G-EPON system

In Japan, the current GE-PON access platform is the main driving force behind FTTH, but studies are underway on a 10-Gb/s version to make FTTH even faster. A 10-Gb/s Ethernet passive optical network (10G-EPON) is being standardized at IEEE.[3] Technical specifications are nearly fixed and standards are scheduled to be completed by September 2009. The GE-PON and 10G-EPON systems are compared in **Table 2**. These systems share the following basic features.

1) Data transport by Ethernet frames
2) One-fiber bidirectional transmission by wavelength division multiplexing (WDM)
3) Continuous signals in the downstream direction and burst-type time division multiple access (TDMA) signals in the upstream direction
4) Fiber transmission distance of 20 km or more and 16 or 32 or more branches

However, 10G-EPON differs from GE-PON in the following points.

1) It provides wavelength bands of 1575–1580 nm in the downstream direction and 1260–1280-nm bands in the upstream direction to support 10-Gb/s transmission.
2) It supports both symmetric and asymmetric transmission modes. The symmetric mode provides 10 Gb/s in each direction while the asymmetric mode provides 10 Gb/s downstream but 1 Gb/s upstream like GE-PON.
3) To provide ten times the transmission capacity, it uses 64B/66B transmission

Table 2
GE-PON versus 10G-EPON.

		GE-PON	10G-EPON
Standard		IEEE 802.3ah	IEEE 802.3av
Class		PX10/PX20	PR10/PR20/PR30 (symmetric) PRX10/PRX20/PRX30 (asymmetric)
MAC layer	Service	Ethernet data	Ethernet data
	Frame	Ethernet frame	Ethernet frame
	Distance	10 or 20 km via single-mode fiber	10 or 20 km via single-mode fiber
Physical layer	Max. branches	16 or more	16 or 32 or more
	Transmission speed	Upstream: 1.25 Gb/s	Upstream: 10.3125 Gb/s or 1.25 Gb/s
		Downstream: 1.25 Gb/s	Downstream: 10.3125 Gb/s
	Transmission capacity	1 Gb/s (8B/10B transmission code)	10 Gb/s (64B/66B transmission code)
	Optical channel loss	20 or 24 dB	20, 24, or 29 dB
	Wavelength	Upstream: 1260–1360 nm Downstream: 1480–1500 nm	Upstream: 1260–1280 nm (10 Gb/s)/PR support Upstream: 1260–1360 nm (1 Gb/s)/PRX support Downstream: 1575–1580 nm (10 Gb/s)/PR/PRX support
	Forward error correction	Optional Reed-Solomon RS (255, 239)	Mandatory Reed-Solomon RS (255, 223)
	Upstream-signal PON header	Laser on/off: 512 ns max Receiver set: 400 ns max Clock extraction: 400 ns max Delimiter: 32 bits	Laser on/off: 512 ns max Receiver set: 800 ns max (sync pattern) Clock extraction: 400 ns max Delimiter: 66 bits
Coexistence		(Video overlay)	GE-PON (video overlay)

PR/PRX: power budgets defined in the specifications

coding like 10-Gb/s Ethernet while GE-PON uses 8B/10B coding like 1-Gb/s Ethernet.

4) Forward error correction (FEC) is mandatory in 10G-EPON, while it is optional in GE-PON. The Reed-Solomon RS (255, 223) code, which provides enhanced error correction, is expected to improve optical minimum sensitivity.

5) A bit-synchronization pattern and byte-synchronization delimiter pattern are defined for burst reception of 10-Gb/s signals in the upstream direction.

Furthermore, an optical budget class of 29-dB fiber loss has been added for 10G-EPON, in addition to the 20- and 24-dB ones for GE-PON, taking into account the need for coexistence with the existing system.

The aim is to enable GE-PON and 10G-EPON to coexist and to continue using the existing optical distribution network (ODN) consisting of optical fibers and couplers. A "dual-rate mode" has also been specified as an optional OLT function to enable a smooth transition from the existing system. An outline of the coexistence of 1- and 10-Gb/s systems is shown in **Figure 4**. Here, the widely used abbreviations 1G and 10G denote data transmission rates that are close to 1 and 10 Gb/s, respectively. In principle, the same coupler can accommodate three types of ONUs: the existing ONU (upstream: 1G, downstream: 1G), a 1G/10G asymmetrical 10G-EPON ONU (upstream: 1G, downstream: 10G), and a 10G/10G symmetrical 10G-EPON ONU (upstream: 10G, downstream: 10G). The OLT transmits continuous 1G and 10G signals in the downstream direction by WDM while receiving 1G and 10G burst signals in the upstream direction by TDMA. This situation is explained in more detail in **Figure 5**. In the downstream direction, GE-PON and 10G-EPON perform WDM transmission in the 1480–1500-nm and 1575–1580-nm wavelength bands, respectively.

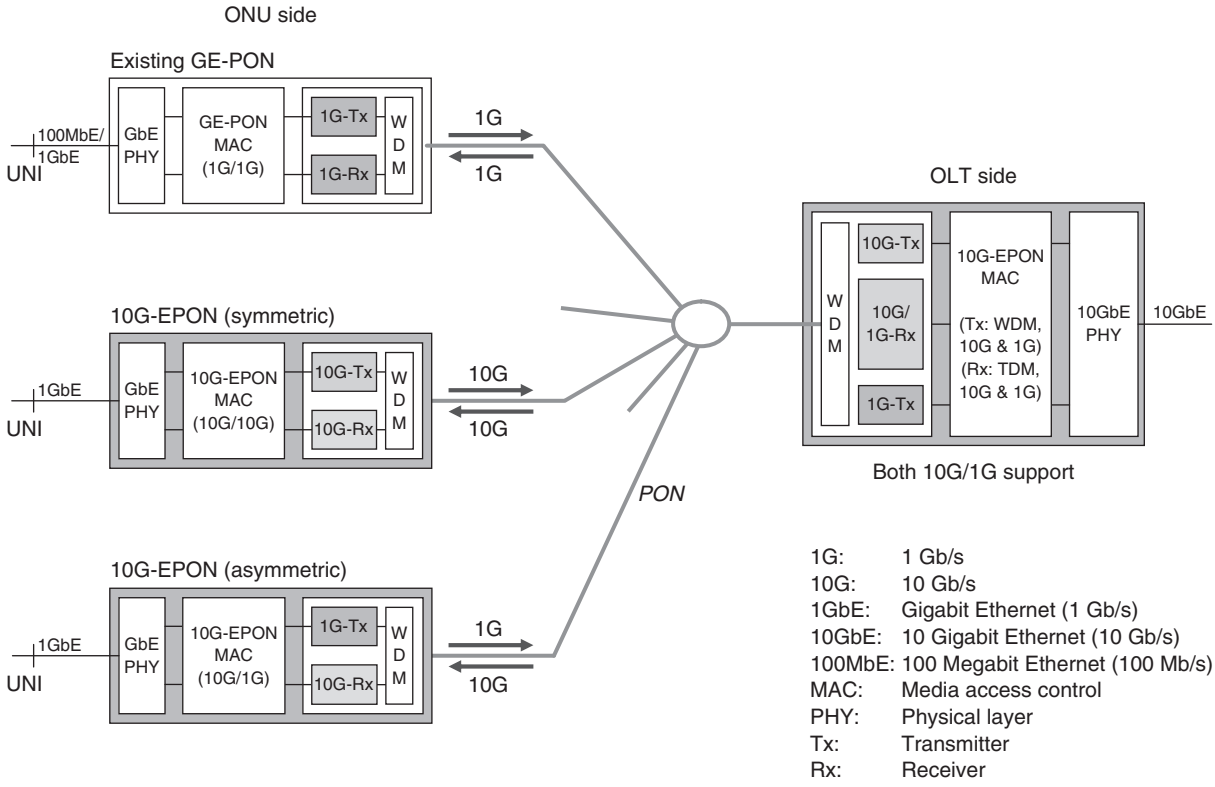


Figure 4
Co-existence of GE-PON and 10G-EPON.

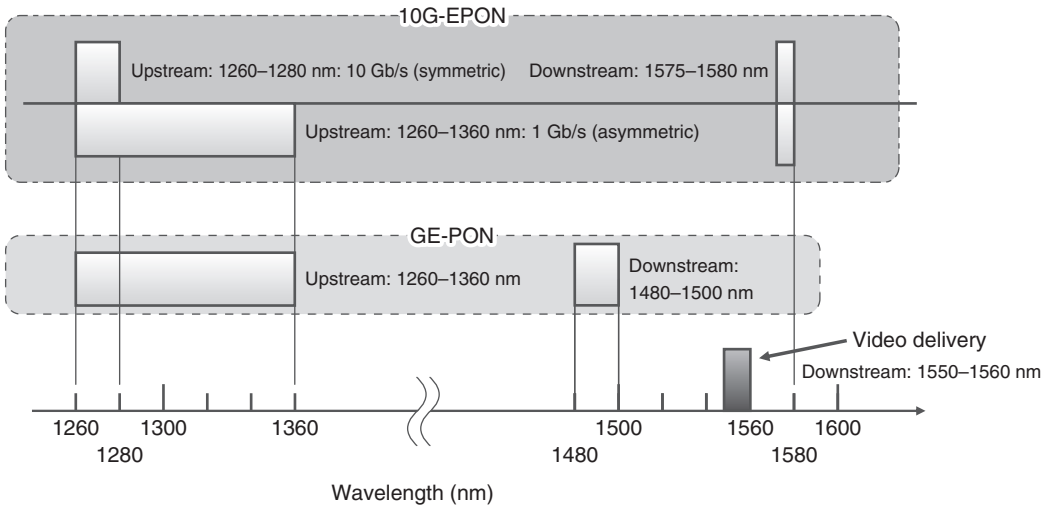


Figure 5
Wavelength allocation of GE-PON and 10G-EPON.

In the upstream direction, GE-PON performs TDMA transmission of burst signals in the 1260–1360-nm wavelength band while 10G-EPON does the same in the 1260–1280-nm (symmetric) or 1260–1360-nm (asymmetric) wavelength band.

The technical objectives of applying 10G-EPON to the access system have already been met by prototype systems, but the system cost is still a high barrier. This is particular true for the development of optical modules, such as high-output 10-Gb/s directly modulated distributed feedback laser optical transmitters for use with upstream signals (ONU) and optical receivers that can receive both 10-Gb/s and 1-Gb/s upstream burst signals (OLT). This equipment needs to be manufactured at lower cost with good production yields.

8. Future technology trends

In the standardization of the high-speed PON interface described above, IEEE is currently ahead of the International Telecommunication Union, Telecommunication Standardization Sector (ITU-T). However, ITU-T has already completed specifications for 2.5-Gb/s G-PON in the downstream as the G.984 series of Recommendations. The plan at ITU-T is to continue with standardization of a high-speed version of PON as the G.987 series of Recommendations in the current study period (2009–2012).

At the same time, IEEE and ITU-T are looking to collaborate on PON-system and optical-interface specifications and on countermeasures to global warming by pursuing low-power-consumption techniques. Two systems are being considered as a next-generation PON: one designed to provide a transition constrained by existing ODN requirements and one unconstrained by existing ODN requirements. In both cases, discussions must address a system with enhanced long-distance and multi-branch features and the application of a wireless detection system. For the latter, clean-slate system, discussions must address a wavelength-based logical point-to-point WDM-PON achieved by replacing existing couplers with couplers that incorporate WDM filters and by using dense WDM and colorless ONUs.

Fujitsu will move forward with G-PON technology development while keeping a close eye on standardization trends and discussions at IEEE and on the activities of the Full Service Access Network (FSAN) interest group, which debates and discusses ITU-T Recommendations and pre-recommendation drafts and contributes papers and proposals to ITU-T.

9. Conclusion

We outlined the GE-PON system, describing its technologies and standardization trends and pointing out its role in promoting FTTH and driving the conversion of the access network to optical fiber in Japan. Recognizing that challenging issues remain in terms of cost and technology, we plan to work on the enhancement and transition of GE-PON as an access platform while watching the standardization activities surrounding 10G-EPON, the high-speed version of GE-PON. Through these efforts, Fujitsu aims to provide a stress-free, environmentally friendly access platform that will enable FTTH users to enjoy an extensive lineup of services including video delivery.

References

1) Ministry of Internal Affairs and Communications (MIC) Press Release: Number of Broadband Service Contracts, Etc. (as of the end of December 2008).
http://www.soumu.go.jp/main_sosiki/joho_tsusin/eng/Releases/Telecommunications/news090318_1.html
2) IEEE P802.3ah.
http://www.ieee802.org/3/ah/
3) IEEE P802.3av Task Force: 10 Gb/s Ethernet Passive Optical Network.
http://www.ieee802.org/3/av/

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