

Application of Ethernet Technologies to FTTH Access Systems

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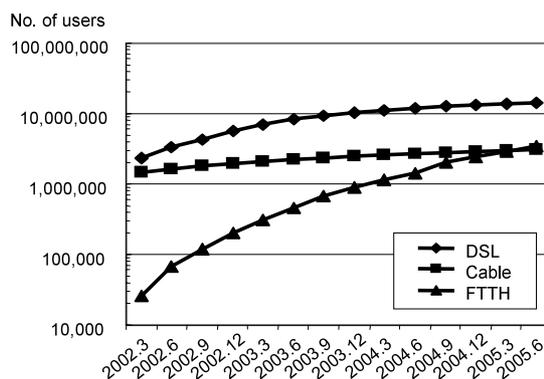
SUMMARY A significant growth in FTTH access rates has been seen in the last year. This paper overviews the deployed FTTH access systems and the recent application of Ethernet technologies. The standardization activities and further study issues are also discussed.

key words: FTTH, Ethernet, point-to-point, B-PON, GE-PON

1. Introduction

The number of the high-speed Internet access users, those with broadband access, has reached 20 million. Of particular interest is the significant growth introduction number of fiber-to-the-home (FTTH) access users. Commercial FTTH in Japan started in 1997 and provides residential plane-old-telephone-service (POTS) and CATV signals transmission by using a combination of synchronous-transfer-mode (STM) passive optical network (PON) [1] and sub-carrier modulation (SCM) PON [2]. The main purpose of this deployment was to replace old metallic pairs with optical fiber access systems, however, the monthly subscription charges of POTS and CATV signal transmission could not, initially, cover the cost of system deployment.

In 2001, a 10 Mbps bandwidth shared PON system [3] and a two-fiber point to point system were started for small business customers and multi-dwelling unit customers. Asymmetric digital subscriber line (ADSL) systems for residential users have had their transmission speed upgraded every six months; the current speed is over 50 Mbps in the downstream direction. With regard to the monthly subscription charges, they have been significantly reduced over the last five years. The competition between the multiple ADSL access service operators has sparked the remarkable growth in ADSL user number. However, the metallic pair's attenuation with access loop length restricts the maximum transmission speed, users who want stable access have moved to FTTH access. From operators' viewpoint, the capability of FTTH allows the provision of more advanced broadband applications, which are new revenue sources for the operators. Currently, in addition to telecom operators, major power utility companies and DSL service operators are providing FTTH access. The heavy competition among broadband access services is driving operators to deploy higher transmission speed systems, from 10 Mbps to 100 Mbps and



Source : Ministry of public management home affairs, posts and telecommunications Information communications statistics database

Fig. 1 Growth of broadband access in Japan.

1 Gbps, and to provide their services with very low subscription charges. Consequently, the number of new FTTH users has exceeded one hundred thousand per month and the total number reached three million in June 2005 (Fig. 1).

This paper overviews the FTTH access systems deployed for broadband Internet access services. Detailed system features are covered from the viewpoints of Ethernet technologies and standardized specifications. Issues for further study with regard to FTTH access systems are also discussed.

2. Overview of FTTH Access Systems

FTTH access systems for broadband Internet access services consist of both Point-to-point and PON systems. The roadmap of these systems is shown in Table 1.

The point-to-point system uses two fibers or one fiber between an OLT and an ONU. The ONU is called the Media-Converter and converts optical signals to electrical signals and vice versa. The advantage of this system is that operators deploy the system according to the growth of the number of users and it is easy to upgrade the transmission speed line by line. It enables operators to deploy the system in the small start fashion. Furthermore, from implementation point of view, the system employs the economical conventional Ethernet interface series like 100BASE-FX and 100BASE-LX even though the standard interfaces cannot support the long-reach transmission (~10 km); this necessitated changes to the physical layer (PHY) optical transceiver and receiver specifications. The point-to-point systems are

Manuscript received July 11, 2005.

Manuscript revised September 27, 2005.

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DOI: 10.1093/ietcom/e89-b.3.661

Table 1 Deployed FTTH access systems in Japan.

FTTH access system	Topology	UNI link speed	Applications	Year of deploy.
STM-Shared PON	PON	10Mbps	Individual house	2001
100BASE-FX extension	Point-point	100Mbps	MDU	2001
TS-1000	Point-point	100Mbps	Individual house MDU	2002
B-PON	PON	100Mbps	Individual house	2002
1000BASE-LX extension	Point-point	100Mbps	MDU	2003
GE-PON	PON	100Mbps	Individual house	2004

deployed for both multi-dwelling unit users and individual house users.

The PON system, which is also called point-to-multipoint, shares an OLT and the fiber between the OLT and an optical splitter. Because this system significantly reduces fiber costs and the space occupied by the central office equipment, it enables operators to minimize investment needed for large scale provisioning. From the technical point of view, the PON systems were designed and specified to meet the incumbent telecom operators' requirements, therefore, the system has employed the well-designed and mature operation, maintenance and administration (OAM) functions. System cost has been also reduced over the last five years and the current system supports up to 1 Gbps transmission. This explains why operators prefer to deploy PONs for residential individual house users.

One of the most significant features of current FTTH systems is that they never support conventional telephony services (i.e. POTS and ISDN). These systems are focused on data communication services and do not need to offer the mandatory functions for telephony services, which are line powering, backup powering battery, transmission clock synchronization with public switched telephone networks (PSTN) and so on. Instead, they provide economical Ethernet interfaces at both the network node interface (NNI) and the user network interface (UNI). This simplified system functionalities bring in their cost reduction.

While Ethernet technologies help to reduce system cost, "genuine Ethernet" specified in IEEE Std. 802.3, has never used for the transmission link between ONU and OLT up to the end of 2004. The reason is that enterprise level local area network (LAN) Ethernet does not support the three important requirements for access systems; transmission length, transmission media, and OAM. Standard Ethernet provides fiber-optic interfaces; 100BASE-FX uses two multi-mode fibers over 2 km reach while 1000BASE-LX uses two single-mode fibers with 5 km reach. Access networks, however, has loop lengths of up to 10 or 20 km with single-mode fiber transmission (single line) and line status check and remote equipment diagnostic OAM functions are needed at the central office. To meet these requirements, the systems employed propriety PHY specifications and OAM

functionalities. This weakened the inter-operability between different vendors and is raising obstacles to further system cost reductions.

3. Details of FTTH Access Systems

Several FTTH access systems have been deployed over the last five years as listed in Table 1. The three most recent FTTH access systems, TS-1000 100 Mbps one-fiber point to point system, Broadband PON (B-PON) and Gigabit Ethernet PON (GE-PON), accommodate the large number of current FTTH users. In this section, we discuss these systems from the aspects of their technical features and standardized specifications.

3.1 One-Fiber Point to Point System (TS-1000)

TS-1000 [4] is a 100 Mbps single single-mode fiber point-to-point system specified by Telecommunication Technology Committee (TTC) Japan in May 2002. Before TS-1000 specification, the PHY and OAM functionalities of the point-to-point systems were implemented in various ways by system vendors and operators. This variation resulted in poor inter-operability between OLT and ONU. Convergence was driven by the FTTH market competition, operators wanted the one single-mode fiber point-to-point system to save fiber costs and reduce network costs. Against this background, system specification studies were started by TTC.

TS-1000 specifies a Physical Media Dependent (PMD) sub-layer optical interface and an OAM sub-layer. As Fig. 2 shows, other sub-layers are compliant with the 100BASE-FX Ethernet interface. Thus existing Ethernet components are easily re-used in system implementation. The TS-1000 PMD employs a wavelength division multiplexing (WDM) for one fiber bi-directional transmission; 1.31 μm wavelength for ONU to OLT (upstream) and 1.53 μm wavelength for OLT to ONU (downstream) transmission. The TS-1000 OAM employs 12-octet OAM short frames as the OAM channel between ONU and OLT. The OAM sub-layer of TS-1000 is located between PHY and Media Access Control (MAC). Therefore, a simple media converter that directly connects optical PHY (TS-1000 PHY) and to metallic PHY (i.e. 100BASE-TX) can support OAM. The supported OAM functionalities include remote fault detection, loop-back testing and UNI status.

The 100BASE-BX10 interface specification, which is one of PHY specifications issued as IEEE Std. 802.3ah in 2004, is based on that of TS-1000. However, the 12-octet OAM short frame of TS-1000 does not meet the minimum Ethernet frame size (64-octet) and is not supported by IEEE802.3. For that reason, TS-1000 is not a "genuine Ethernet."

After release of the TS-1000 specification, compliant systems have produced in Japan as well as other major Asian countries. This has yielded significant system cost reductions. The systems have been widely deployed to both multi-

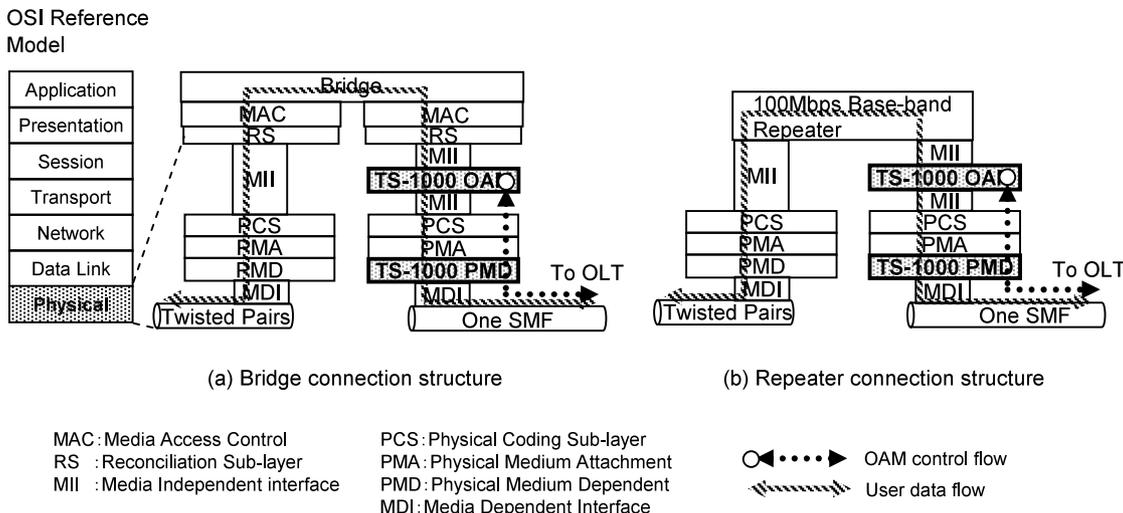


Fig. 2 Typical TS-1000 protocol stack structure.

dwelling unit (MDU) and individual house users. In the case of MDU deployment, the link between the ONU and each dwelling unit employs very-high-bit-rate DSL (VDSL). In this configuration, the ONU and optical fiber are shared by multiple users and existing metallic pairs can be used as the connection to the dwelling units. Consequently, operators are able to provide broadband access services to users with the same cost as typical DSL access.

3.2 B-PON

Although TS-1000 reduced the number of fibers and offers lower network equipment costs than conventional point-to-point systems, further cost reductions are required to deploy FTTH to individual residential users. The PON architecture shares an OLT and a fiber between the OLT and a splitter with multiple users. Consequently, it is possible to minimize the amount of fiber in access networks as well as OLT number.

B-PON is an Asynchronous Transfer Mode (ATM) PON specified in ITU-T G.983 series [5], [6]. This system was originally designed to transmit various Time Division Multiplexing (TDM) services over ATM cells, and to provide traffic control to the ATM layer. B-PON provides a wide variety of transmission speeds, and operators can freely choose their favorite combination: 155 Mbps, 622 Mbps, or 1.25 Gbps downstream, with 155 Mbps or 622 Mbps upstream. The most widely deployed B-PON employs the combination of 155 Mbps upstream and 622 Mbps downstream. The OAM channels between the OLT and optical network terminal (ONT: equivalent to ONU) are established by physical layer OAM cells (PLOAM) in the Transmission Convergence (TC) layer and OAM ATM cells in the ATM layer. All of the OAM functionalities desired by operators can be provided over these OAM channels. Current B-PON systems from different vendors are interoperable because of the detailed specifications and interoperability tests organized by Full Service Access Network (FSAN)

and ITU-T. Furthermore, using the 1.31 μm wavelength for upstream and 1.49 μm wavelength for downstream as specified in ITU-T G.983.3 allow multi-channel video broadcasting services to be easily overlaid on the same PON network by using 1.55 μm wavelength signals with WDM [7]. These features of B-PON are the reason why operators who are planning to provide full-service (Video, High-speed Internet and POTS) prefer to deploy B-PON.

The B-PON deployed in Japan focuses on residential 100 Mbps Internet access services and the system has no ATM and POTS interfaces in either the ONU or OLT. This simplifies the system functionalities and minimizes system costs as shown in Fig. 3.

B-PON supports Dynamic Bandwidth Allocation (DBA) [8] and cell controls in the ATM layer to ensure the PON section QoS. Even if the PON bandwidth is shared by multiple users, it is possible to provide multi-class Ethernet access services. It has been pointed out that the point-to-point system has an advantage over the PON system since the former provides exclusive bandwidth. When all ONUs transmit or receive high-speed constant bit rate (CBR) traffic (i.e. 100 Mbps), this is a valid point. However, actual Ethernet traffic today is bursty and fluctuates heavily at the time scale of milliseconds [9]. By using the appropriate DBA cycle (i.e. a few milliseconds) and appropriate buffer size, there is no significant throughput difference between B-PON and point-to-point systems.

3.3 GE-PON

IEEE 802.3 WG, a well-known body responsible for developing Ethernet standards, formed the IEEE 802.3ah (known as EFM: Ethernet in the First Mile) Task Force for the purpose of developing a new broadband access standard in 2001 [10]. The coming standard is intended to take advantage of the outstanding economy, interoperability, and high-speed, broadband capabilities of Ethernet. As described before, the conventional Ethernet series did not offer the per-

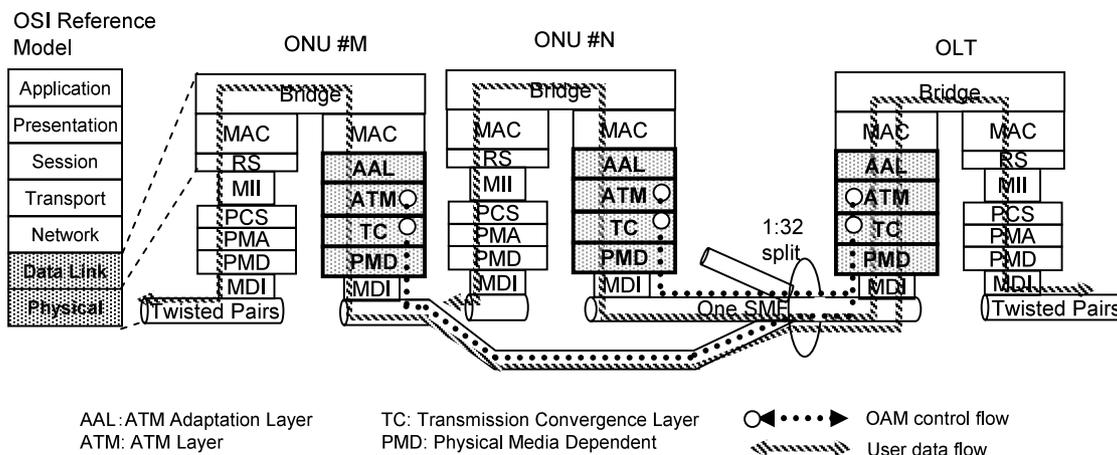


Fig. 3 B-PON deployed in Japan protocol stack structure.

Table 2 EFM Series.

Interface name	Topology	Media	Transmission Speed	Transmission Length
2BASE-TL	P2P	Copper Pairs	2Mbps	2700m
10PASS-TS	P2P	Copper Pairs	10Mbps	750m
100BASE-LX10	P2P	Two Fibers	100Mbps	10Km
100BASE-BX10	P2P	One Fiber	100Mbps	10Km
1000BASE-LX10	P2P	Two Fibers	1Gbps	10Km
1000BASE-BX10	P2P	One Fiber	1Gbps	10Km
1000BASE-PX10	P2MP	One Fiber	1Gbps	10Km
1000BASE-PX20	P2MP	One Fiber	1Gbps	20Km
OAM				
<ul style="list-style-type: none"> • Remote failure identification • Remote loop-back • Link monitoring • OAM discovery 				

formance required for access network deployment. EFM, therefore, started to develop a new interface series that includes metallic twisted pair and single mode fiber media, up to 10 km/20 km transmission reach, and OAM as shown Table 2. One of the most interesting things is that this new series offers the PON topology.

The name of GE-PON is not authorized in IEEE Std. 802.3ah. The optical interface name is 1000BASE-PX10 or 1000BASE-PX20, and Ethernet PON (EPON) or Point-to-Multi-Point (P2MP) are written as the reference names in the document. The name of EPON has already used by proprietary PONs in Japan. Therefore, to draw a clear distinction between them, and to emphasize 1 Gbps bandwidth, GE-PON is widely used in Japan.

To realize PON, a mechanism to avoid data frame collision in the upstream direction is necessary. Conventional Ethernet provides the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access mechanism for shared transmission media. However, the transmission

length of 1 Gbps speed with CSMA/CD is limited within 200 m. Furthermore, an ONU cannot detect the signals from the other ONUs accommodated in the same PON because optical signals from the ONUs are not reflected at the splitter. Therefore, the Multi-Point Control Protocol (MPCP), which is a variant of time division multiple access (TDMA), was developed.

The expanded or newly developed sub-layers of GE-PON are shown in Fig. 4; other sub-layers are basically reused from earlier IEEE802.3 specifications.

3.3.1 Physical Layer

The physical layer of GE-PON consists of the Physical Media Dependent sub-layer (PMD), Physical Media Attachment (PMA) sub-layer, and Physical Coding Sub-layer (PCS). The specifications of these sub-layers mainly focus on the optical transceiver and receiver. An overview of these specifications is shown in Table 3. For bi-directional transmission over one single-mode fiber, the ITU-T G.983.3 wavelength plan is applied. The parameters of PMD were expected to use ITU-T G.984 series gigabit-capable PON (G-PON) [11], which was studied around the same time, for PMD cost reductions. However, the parameters for burst transceiver and receiver were relaxed compared to the ITU-T specifications, which are laser_on/off time = 16 ns, sync_time = 96 ns and extinction_ratio ≥ 10 dB. This parameter relaxation is mainly intended to permit the reuse of the conventional 1000BASE-X PMD and achieve further cost reductions on the ONU side. An optional feature of the physical layer is forward error correction (FEC) in PCS, which improves bit-error rate and thus the transmission length.

3.3.2 Reconciliation Sub-Layer (RS)

RS provides a signal-map function between PHY and the media access control sub-layer (MAC). In the PON architecture, it is essential to identify and forward the data frames

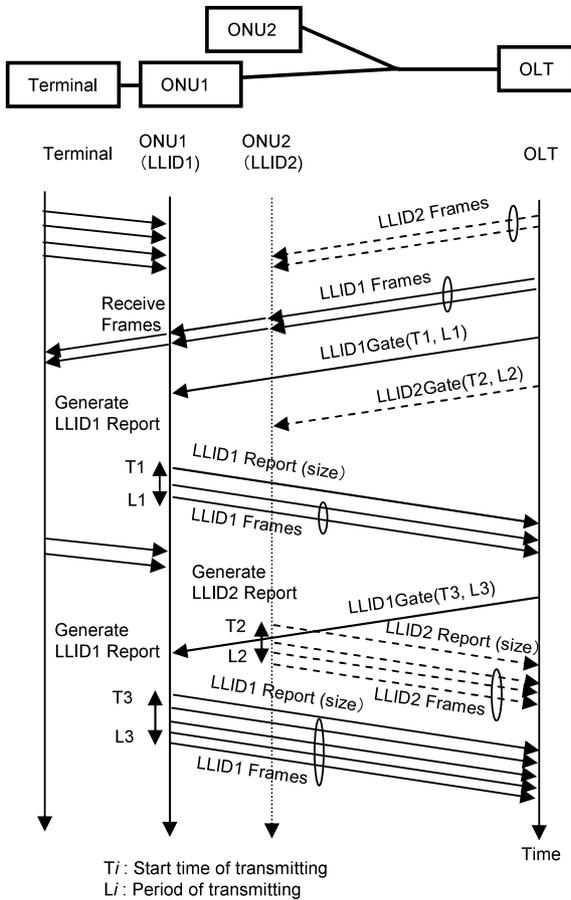


Fig. 5 MPCP sequence flow.

because MPCP is not activated without DBA. DBAs will be prepared by system implementers or service providers based on their service specifications [12], [13]. The PMD parameters values employed and number of LLIDs supported by the OLT is also based on the service specifications. These specifications can be regarded as differentiating the systems. Furthermore, although the standard states that each ONU has but one LLID, it is possible to associate multiple LLIDs with one ONU. To implement this architecture, the ONU is treated as multiple virtual ONUs and each virtual ONU can be controlled by DBA [14], [15]. These variations, which are interoperable with the standard, increase the flexibility of system implementation and future service capabilities.

The most critical implementation issue is encryption of the PON section. Since the PON architecture shares the same media, all ONUs receive all downstream data and ONUs are assumed to extract only their intended data. Consequently, a malicious user can steal all data. The conventional PON standards provide encryption or data scrambling methods, but there is no common encryption mechanism for GE-PON leading to the implementation of proprietary mechanisms. Leaving this issue unresolved will hinder the future deployment of the GE-PON system [16], [17].

4. Study Issues for Applications of Ethernet

Ethernet technologies have contributed to lowering the cost of FTTH access systems. Application of the Ethernet standard has expanded from the enterprise LAN to the access network environment. However, the application of Ethernet technologies to the access network systems is still at an intermediate stage of development. There are several points that remain to be improved as follows:

- EFM is preparing a standard OAM, but it provides only the minimum set of functionalities in the Ethernet layer. Therefore, operators must implement the OAM functionalities that are beyond the Ethernet layer or missing in this layer, by referring to other standards or defining private management information base (MIB) and organization-specific extensions. To resolve this issue, ITU-T SG13, SG15 and IEEE802.1WG have developed specifications of carrier-grade Ethernet OAM functions [18].
- GE-PON has no common security mechanism that is interoperable with the default mechanism. A study of link security including data frame encryption and key exchange mechanisms has been organized by IEEE802.1WG [19], [20]. The study group is developing MAC-independent specifications and the scope is to protect the user data payload field in Layer 2. However, as the security link is established above MAC layer, OAM and MPCP control frames of GE-PON are not protected. Therefore, further study of GE-PON security including the development of a GE-PON-dependent mechanism is required.
- Current ONUs, which are the simple bridge type, are provided by service operators. With such service provisioning, the set of standards available today might be enough for system implementation and actual deployment, and there is no serious problem with implementing proprietary functions. However, once ONUs enter the user's home in devices such as cell phones, modems or other digital appliances, a common set of interface specifications for interoperability on the access network side is necessary. For this reason, protocol implementation conformance statements and an ONU test-bed have to be developed.
- Conventional broadband services for residential users were best-effort type. However, FTTH broadband access today covers services from entertainment to commodities. They provide hi-quality voice over IP and digital video multicasting services in addition to Internet access. In order to provide multi-class services over Ethernet, strict traffic segregation and QoS control granularity technologies are also being studied. Furthermore, even if GE-PON provides 1 Gbps transmission speed, the number of channels for HDTV quality digital video broadcasting service is not enough, this limitation demands even higher system speeds. How-

ever, it is necessary to evaluate WDM overlay technologies simultaneously with high-speed transmission.

- As an alternative technology to support conventional PSTN, the application of Ethernet, i.e. TDM over Ethernet, has been discussed. This technology consists of upper layer protocols, traffic flow controls and lower layer transmission, which have been independently developed in different standard bodies. Therefore, their inter-working is essential for standardization. ITU-T SG13 is developing a set of specifications that ensure their cooperation [21].

5. Conclusion

This paper has overviewed deployed FTTH access systems and the recent application of Ethernet technologies. Details of TS-1000, B-PON and GE-PON were reviewed and the use of Ethernet technologies in each system were explained. Ethernet technologies have contributed to the lower costs and higher transmission speeds offered by recent FTTH access systems. We note that as the main technologies of access networks are switching from conventional PSTN to Ethernet, the deficiencies in the functionalities both inside and outside the standards have become looming issues. Standardization activities supported by industrial awareness and studies on Ethernet technologies will provide really viable FTTH access.

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