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Fiber–to–the–Home Technologies and Standards

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INTRODUCTION

Fiber-to-the-home (FTTH) refers to the provisioning of narrowband and broadband services to the residential customer over an optical cable rather than traditional copper wiring. Early trials in the United States, England, and France to provide telephone and broadcast video service to residential customers occurred in the mid- to late 1980s, however, widespread deployment did not follow from these trials (Esty, 1987; Rowbotham, 1989; Shumate, 1989; Veyres & Mauro, 1988). Studies conducted at the time suggested that consumer demand for video and telephone service was not sufficient to warrant the funds necessary for wide-scale deployment of the systems (Bergen, 1986; Sirbu & Reed 1988).

The studies did not foresee the interest in residential broadband service spurred by the growth of the commercial Internet and the World Wide Web. Since the days of the early trials, residential and small-business lines providing at least symmetric 200-kbps services have grown to 18.1 million as of December 2003 in the United States alone (Federal Communications Commission, 2004), and FTTH has been standardized with an eye toward providing multimedia services.

BACKGROUND

Deployment of residential broadband has been growing around the world. The most commonly deployed technologies are DSL and cable modems (Ismail & Wu, 2003). Wireless for residential broadband also has a small showing.

Both DSL (digital subscriber line) and cable modem services run over existing copper or hybrid fiber-copper plants. The newest DSL technology is VDSL, which promises to deliver asymmetric speeds of up to 52 Mbps from the provider to the customer (downstream) and 6 Mbps from the customer to the provider (upstream), or symmetric speeds of 26 Mbps (The International Engineering Consortium, n.d.). Unfortunately the technology is distance limited and the maximum speeds can only be achieved up to a distance of 300 m. Longer distances result in a reduction in speed.

Cable modem services' newest standard, DOCSIS 2.0 (Cable Television Laboratories, Inc., 2004), is capable of a raw data rate of 40 Mbps in the downstream and 30 Mbps in the upstream. However, due to the broadcast nature of the system, this bandwidth is typically shared among a neighborhood of subscribers.

Fixed wireless services are also targeting the residential broadband market with a technology capable of up to symmetrical 134.4 Mbps depending on the width of the channel and the modulation scheme used. The technology is known as WiMax and is defined in IEEE 802.16 (Institute of Electrical and Electronics Engineers (IEEE); IEEE, 2002). The original WiMax standard, and the 134.4-Mbps transmission capability, is for use in a frequency range that requires line of sight for transmission. The standard has since been updated via IEEE 802.16a (IEEE, 2003) for use in frequency bands that do not require line of sight for transmission. The drawback to using non-line-of-sight frequency bands is a lower data rate of up to 75 Mbps depending on channel width and modulation scheme. Similar to cable modem service, WiMax also shares its bandwidth among groups of customers.

The technologies under development for fiber to the home promise far greater dedicated bandwidth than any of the proposed future modifications to DSL, DOCSIS, or fixed wireless, and in the case of DSL, over much longer distances. This makes FTTH better suited as a platform to support multimedia services to residential customers.

FIBER-TO-THE-HOME TECHNOLOGIES AND STANDARDS

FTTH technologies fall into two categories: active or passive. Both types of technologies are capable of delivering voice, video, and data service. Active technologies have an active component such as a switch or router between the central office and the customer. Passive technologies have a passive (unpowered) component, such as an optical splitter, between the central office and the customer.

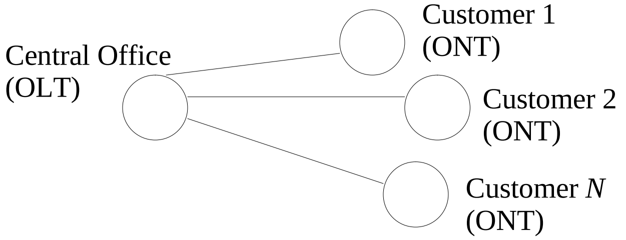
Standards work for FTTH technologies has been taking place in two different organizations: the Institute of Electrical and Electronics Engineers and the Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T). The IEEE standards work is focused on the use of Ethernet-based technologies in the access network (Ethernet in the First Mile or EFM) and the ITU standards work (called recommendations) focuses primarily on passive optical networks (PONs). The ITU-T and IEEE standards groups communicate regularly in order to ensure that the standards that are developed do not conflict.

FTTH technologies can be deployed in three different topologies: home run, active star, or passive star (Committee on Broadband Last Mile Technology, National Research Council, 2002).

Home Run

A home-run network topology is a point-to-point topology with a run of fiber from the provider's central-office optical line terminal (OLT) out to each customer optical network terminal (ONT). The fiber run can be either one fiber, with different wavelengths for upstream and downstream transmission, or two separate fibers, one for upstream and one for downstream transmission. A home-run network topology is shown in Figure 1. This architecture is costly because it requires a dedicated fiber for each customer from the central office to the customer premise. The central-office equipment is the only resource that is shared amongst the customer base.

Figure 1. Home-run topology



ITU-T G.985, approved in March 2003, is defined as operating over a point-to-point network topology. G.985 came out of efforts by the Telecommunications Technology Committee (TTC) in Japan to achieve interoperability between vendors for deployed Ethernet-based FTTH systems (ITU-T, 2003c) and has contributed to the EFM Fiber standards work.

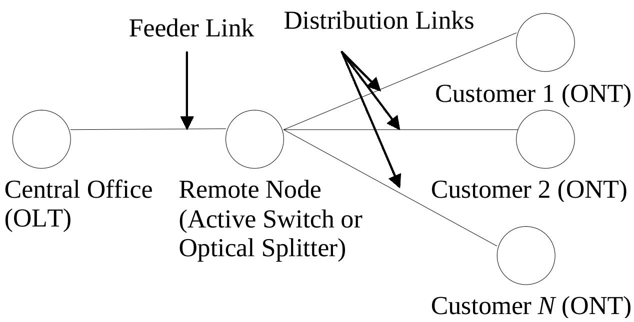
The recommendation describes a single-fiber, 100-Mbps point-to-point Ethernet optical access system. Included are specifications for the optical distribution network and the physical layer, and also the requirements for operation, administration, and maintenance. Transmission is on a single fiber using wave-division multiplexing (WDM), with downstream transmission in the 1480- to 1580-nm range and upstream transmission in the 1260- to 1360-nm range. WDM divides the fiber by wavelength into two or more channels. The standard currently defines a 7.3-km transmission distance with 20- and 30-km distances for further study.

Active Star

In this topology, a remote node with active electronics is deployed between the central office and the customer premises, as shown in Figure 2. The link between the central office and remote node is called the feeder link, and the links between the remote nodes and the customer premises are called distribution links. A star topology is considered more cost effective than a home-run topology because more of the network resources are shared amongst the customers.

EFM Fiber (IEEE 802.3ah) is most commonly deployed in an active star configuration. It is similar in architecture to traditional hubs and switches that run 10BaseF and 100BaseFX today. The standards for EFM Fiber are currently under development in the IEEE 802.3ah Task Force.

Figure 2. Star topology



The technology consists of point-to-point, single-mode fiber with a range of at least 10 km between the active switch and the ONT. EFM Fiber employs Ethernet and active equipment at speeds of 100 Mbps and 1 Gbps (IEEE 802.3ah Ethernet in the First Mile Task Force, 2004). Operation can be over a single fiber or one fiber for upstream transmission and a second fiber for downstream transmission.

For the two-fiber configuration, transmission is in the 1260- to 1360-nm wavelength band. For operation over a single fiber, upstream transmission is in the 1260- to 1360-nm wavelength band and the downstream transmission wavelength varies depending on the transmission speed. 100-Mbps downstream operation uses the 1480- to 1580-nm wavelength band, and 1-Gbps downstream operation uses the 1480- to 1500-nm wavelength band. The wavelength assignments for 1-Gbps service allow the system to incorporate a dedicated wavelength for broadcast video service in the 1550- to 1560-nm bands as specified by the newer ITU-T passive-optical-network standards described in the following section.

Passive Star

Passive optical networks, or passive star topologies, have no active components between the provider's central office and the subscriber. The remote node of Figure 2 contains an optical splitter in a passive star topology. PONs are point-to-multipoint systems with all downstream traffic broadcast to all ONTs. The PONs under development are ATM-based PONs (asynchronous transfer mode; APONs), gigabit-capable PONs (GPONs), and Ethernet-based PONs (EPONs).

ATM PON

APON systems are PONs that are based on the asynchronous transfer mode. APONs are also known by the name of BPON, or broadband PON, to avoid confusing some users who believed that APONs could only provide ATM services to end users. APONs are defined by the ITU-T G.983 series of recommendations.

ATM uses 53-byte cells (5 bytes of header and 48 bytes of payload). Because of the fixed cell size, ATM implementations can enforce quality-of-service guarantees, for example, bandwidth allocation, delay guarantees, and so forth. ATM was designed to support both voice and data payloads, so it is well suited to FTTH applications.

The APON protocol operates differently in the downstream and upstream directions. All downstream receivers receive all cells and discard those not intended for them based on ATM addressing information. Due to the broadcast nature of the PON, downstream user data is churned, or scrambled, using a churn key generated by the ONT to provide a low level of protection for downstream user data.

In the upstream direction, transmission is regulated with a time-division multiple access (TDMA) system. Transmitters are told when to transmit by receipt of grant messages. Upstream APON modifies ATM and uses 56-byte ATM cells, with the additional 3 bytes of header being used for guard time, preamble bits, and a delimiter before the start of the actual 53-byte ATM cell.

The G.983 series of recommendations define the nominal bit rates for APON to be symmetric 155.52 Mbps or 622.08 Mbps, or asymmetric 622.08 Mbps in the downstream direction and 155.52 Mbps in the upstream direction. The OLT for an APON deployment can support multiple APONs with a split ratio of 32 or 64 subscribers each, depending on the vendor.

ITU-T G.983.1, approved in October 1998, can be deployed as two fibers to each customer (one upstream and one downstream), or, using WDM, as one fiber to each customer. For two fibers, transmission is in the 1260- to 1360-nm band in both upstream and downstream directions. In a single-fiber system, upstream transmission remains in the 1260- to 1360-nm band and downstream transmission is in the 1480- to 1580-nm wavelength band (ITU-T, 1998).

ITU-T G.983.3, approved in March 2001, redefines the downstream transmission band for single-fiber APONs. This allows part of the spectrum to be allocated for video broadcast services or data services. Services can be either bidirectional or unidirectional (ITU-T, 2001).

The wavelength allocations leave the PON upstream wavelengths unchanged at 1260 to 1360 nm. The downstream transmission band is reduced to only include the portion of the band from 1480 to 1500 nm, called the basic band. The enhancement band (Option 1), the 1539- to 1565-nm band, is for the use of additional digital services. The recommendation defines the 1550- to 1560-nm band as the enhancement band (Option 2) for video-distribution service. Two bands are reserved for future use: the band from 1360 to 1480 nm, which includes guard bands, and a future L band in the 1480- to 1580-nm range for further study and allocation.

Gigabit PON

Efforts to standardize PON networks operating at above 1 Gbps were initiated in 2001 as the ITU-T G.984 series of recommendations. GPON is a more generalized version of APON and is not dependent on ATM. GPON realizes greater efficiency over APON by not requiring large IP (Internet protocol) packets to be broken up into 53-byte ATM cells. GPON attempts to preserve as many characteristics of the G.983 series of recommendations as possible, however, due to technical issues relating to providing the higher line rates, the two systems are not interoperable (ITU-T, 2004).

As with APON, the system may be either a one- or two-fiber system. In the downstream direction, GPON is also a broadcast protocol with all ONTs receiving all frames and discarding those not intended for them. Upstream transmission is via TDMA and is controlled by an upstream bandwidth map that is sent as part of the downstream frame. GPON uses encryption for the payload. The encryption system used assumes that privileged information, like the security keys to decode the payloads, can be passed upstream in the clear due to the directionality of the PON (i.e., that any ONT in the PON cannot observe the upstream traffic from any other ONT in the PON).

The GPON OLT can support split ratios of 16, 32, or 64 users per fiber with current technology. ITU-T (2003b) G.984.2 anticipates future ratios of up to 128 users per fiber and accounts for this in the transmission-convergence layer. As with G.983.3, for a single-fiber system, the operating wavelength is in the 1480- to 1500-nm band in the downstream and in the 1260- to 1360-nm band in the upstream. This leaves the 1550- to 1560-nm band free for video services. For a two-fiber system, the operating wavelength is in the 1260- to 1360-nm band in both the downstream and the upstream directions.

GPON has seven transmission-speed combinations (line rates): symmetric 1.2 or 2.4 Gbps; or asymmetric 1.2 or 2.4 Gbps downstream with 155 Mbps, 622 Mbps, or 1.2 Gbps in the upstream (ITU-T, 2003a). The physical reach of the GPON is 10 km for speeds of 1.2 Gbps and below, and 20 km for speeds above 1.2 Gbps.

Ethernet PON

EPON is Ethernet over a passive optical network. Similar to EFM Fiber, standards are being developed in the IEEE 802.3ah Task Force. The protocol used in EPON is an extension of Ethernet (IEEE 802.3) and operates at 1 Gbps with a range of 10 or 20 km between the central office and the customer. The architecture is a single shared fiber with an optical splitter, as with other PON architectures. The supported split ratio is 16 users per PON. The system operates in the 1480- to 1500-nm band in the downstream direction, and in the 1260- to 1360-nm band in the upstream direction. As with 1-Gbps EFM Fiber, while not specifically mentioning a wavelength for broadcast video service, EPON allocates its wavelengths to leave the 1550- to 1560-nm band open and is capable of supporting a broadcast video wavelength in that band.

Since Ethernet does not utilize a point-to-multipoint topology, EPON required the development of a control protocol to make the point-to-multipoint topology appear as a point-to-point topology. This protocol is called the multipoint control protocol (MPCP).

Like all PONs, in the downstream direction EPON is a broadcast protocol. Every ONT receives all packets, extracts the Ethernet frames intended for that customer, and discards the rest. As with APON and GPON, transmission in the upstream direction is regulated by TDMA.

Table 1. FTTH single-fiber system summary

Technology	1550-nm Video	Max. Speed (Mbps)	Homes per Feeder	Standard	Year
G.985	No	100	N/A	G.985	2003
EFM Fiber	No Yes	100 1,000	N/A	802.3ah	2004
APON	No Yes	622	1,632	G.983.1 G.983.3	1998 2001
GPON	Yes	2,400	64, 128	G.984	2003
EPON	Yes	1,000	16	802.3ah	2004

FUTURE TRENDS

As shown in Table 1, FTTH standards are moving toward higher line speeds, more users per PON, and standardized wavelengths with the ability to provide a dedicated wavelength for broadcast video service. The GPON recommendations anticipate some of these trends by allowing for wavelengths for future expansion, and the possibility of higher split ratios and line speeds in the formulation of the standard.

The standards for EFM Fiber and G.985 do not specify the number of homes that must be supported per feeder fiber. This allows the systems to be deployed in either an active star or home-run topology supporting as many users as current switching technology is capable of without the need to modify the standard. In some current active star implementations, the number of homes per feeder fiber supported is as high as 48. This number is expected to increase as switching technology improves.

CONCLUSION

The ITU and IEEE are working to develop FTTH standards that do not conflict with one another. These standards are converging toward standardized wavelength allocations for upstream and downstream transmission with the ability to support a consistent, dedicated wavelength for broadcast video service. The standards are also moving toward higher line speeds and the ability to support more users.

Fiber to the home provides greater bandwidth than any of the residential networking alternatives. With the addition of an entire 1-GHz wavelength for broadcast video in the standards for EFM Fiber, EPON, G.983.3 APON, and GPON, FTTH can support HDTV (high-definition television) channels and video-on-demand functions without competing with voice or data bandwidth, making it well suited for multimedia applications.

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KEY TERMS

APON or Broadband PON (APON/BPON): APON is defined by the ITU-T G.983 series of recommendations. It features a passive optical network for fiber-to-the-home service that uses ATM as its transmission protocol. BPON is an alternate name for this technology.

Broadband: The U.S. Federal Communications Commission defines broadband to be any high-speed digital technology that provides integrated access to high-speed data, video-on-demand, and interactive delivery services with a data rate of at least 200 kbps in one direction.

EFM Fiber: EFM Fiber is defined by IEEE 802.3ah. It features a point-to-point fiber-to-the-home network, typically deployed as an active star, that uses active electronics and Ethernet as its transmission protocol.

Ethernet PON (EPON): EPON is defined by IEEE 802.3ah. It features a passive optical network for fiber-to-the-home service that uses Ethernet as its transmission protocol.

Fiber-to-the-Home (FTTH): The use of fiber-optic cable for the provisioning of narrowband and broadband services to the residential customer rather than traditional copper wiring.

Gigabit PON (GPON): GPON is defined by the ITU-T G.984 series of recommendations. It features a passive optical network for fiber-to-the-home service that is capable of providing at least 1 Gbps service in the downstream direction.

Narrowband: A transmission path that is capable of 64 kbps transmission and voice-grade service.

Optical Line Terminal (OLT): A fiber-to-the-home terminating device at the provider's central office or point of presence connected to one or more PONs that provides connection to the provider's network.

Optical Network Terminal (ONT): A fiber-to-the-home terminating device at the customer premise.

Passive Optical Network (PON): An optical transmission path from the provider to the customer that contains only unpowered optical components, such as optical splitters and splices.