

Deployment Status and Common Technical Specifications for a B-PON System

Hiromi Ueda and Kenji Okada, Nippon Telegraph and Telephone Corporation

Brian Ford and Glenn Mahony, BellSouth

Stephen Hornung and David Faulkner, British Telecom plc.

Jacques Abiven and Sophie Durel, France Telecom

Ralph Ballart and John Erickson, SBC

ABSTRACT

Broadband passive optical networks (B-PONs) have entered the commercial deployment phase in North America, Japan, and Europe. Nippon Telegraph and Telephone, BellSouth, France Telecom, British Telecommunications plc, and SBC have developed a set of common technical specifications for a B-PON system based on ITU-T Recommendations G.983.1, G.983.2 and G.983.3. They have deployed or plan to deploy B-PON systems based on this CTS. This article describes B-PON interface features, the outline of CTS, and the deployment status of the B-PON systems around the world.

INTRODUCTION

Broadband passive optical network (B-PON) is the most promising approach to establishing a cost-effective optical access network; it achieves its excellent economy because multiple users share optical fiber and office equipment. Its

specifications were originally discussed and determined in Full Services Access Network (FSAN) [1], which is an international group formed by carriers and vendors. It is also standardized in International Telecommunication Union — Telecommunication Standardization Sector (ITU-T) Recommendations G.983.1 [2], G.983.2 [3] and G.983.3 [4]. For a concise historical explanation of the term B-PON, the reader is directed to the companion articles in this issue.

If an optical access network for broadband services is to succeed, we have to reduce system cost substantially. This is best achieved by establishing a set of common specifications. Cost is reduced in two ways: stronger competition between suppliers and increased production volumes, which allows the learning curve effect to have a greater impact on production costs [5].

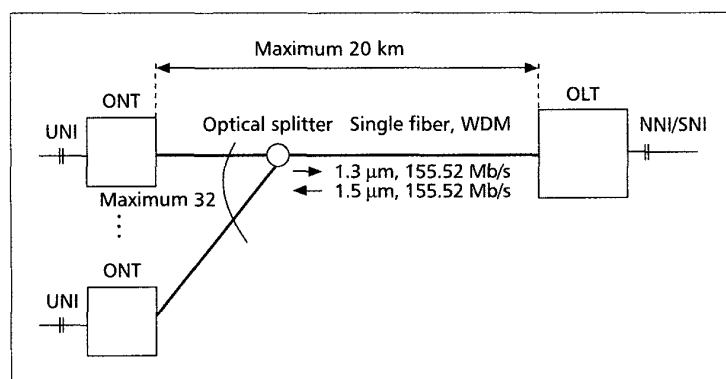
NTT and BellSouth formed the first collaborative effort toward developing a common technical specification (CTS) for the B-PON system in July 1998. BT and France Telecom joined them in June 1999; SBC joined in August 2000. The CTS was continually revised over this period. Now five operators use the same CTS when specifying B-PON systems.

NTT, BellSouth, BT, FT, and SBC have deployed and have a plan to deploy B-PON systems based on the CTS, which complies with ITU-T Recommendations G.983.1, G.983.2, and G.983.3.

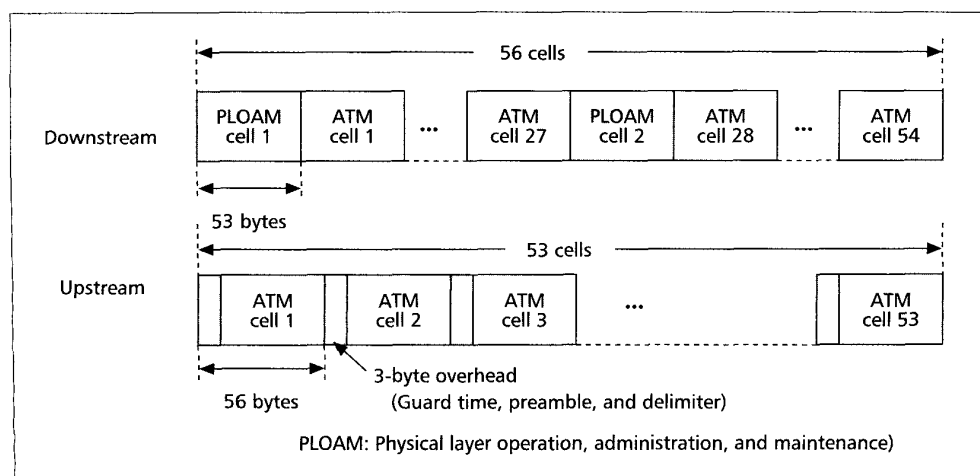
This article overviews the B-PON interface technology described in Recommendation G.983.1, and describes the CTS developed by NTT, BellSouth, BT, FT, and SBC. In addition, this article describes the current B-PON system deployment status of NTT, BellSouth, BT, FT, and SBC.

B-PON INTERFACE FEATURES

This section describes the B-PON interface features that were originally created by FSAN and



□ Figure 1. An example of B-PON system configuration.



□ Figure 2. Basic frame structure for B-PON.

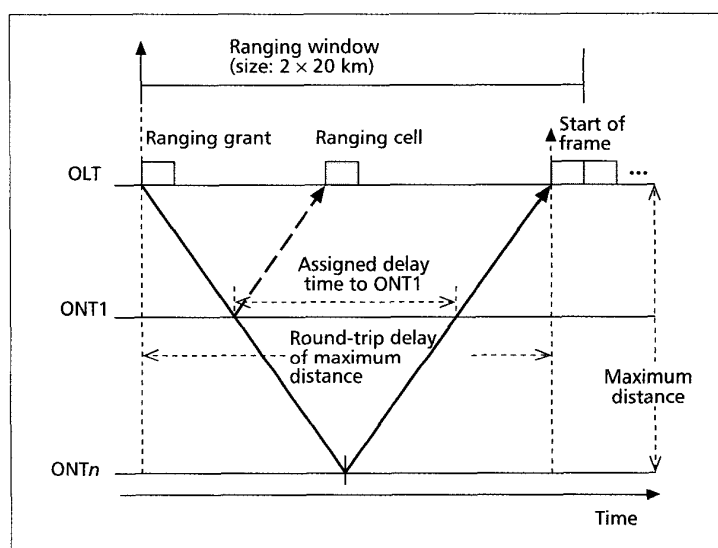
then formalized in ITU-T Recommendations G.983.1 [2], G.983.2. [3], and G.983.3 [4]. G.983.1 focuses on the physical layer and transmission convergence layer, while G.983.2 specifies the management interface between the optical line terminal (OLT) and the optical network terminal (ONT). G.983.3 specifies an additional wavelength band over B-PON that can be used for downstream video broadcast or bidirectional transport using dense wavelength-division multiplexing (DWDM).

There are two PON options: a symmetric 155.52 Mb/s, and an asymmetric 622.08 Mb/s down to the customer and 155.52 Mb/s from the customer. The system can operate on either one fiber using WDM or two fibers.

An example of the symmetric 155.52 Mb/s WDM B-PON system configuration is shown in Fig. 1. The optical fiber, connected to the OLT, located at a central office, branches at the optical splitter into no more than 32 fibers. These fibers are connected to ONTs in customer premises or buildings. The optical fiber located on the office side of the optical splitter and the OLT are shared by all ONTs connected to the splitter. Maximum transmission distance between an OLT and an ONT is 20 km.

Figure 2 shows the basic frame structure of the 155.52 Mb/s upstream and downstream signals. In the upstream direction, the basic frame contains 53 cell slots, each 56 bytes long. Each cell slot consists of a 53-byte ATM cell and 3-byte overhead, which is used to hold guard time, preamble, and delimiter. In the downstream direction, the basic frame contains 56 cell slots, each 53 bytes long, to carry 54 ATM user cells and two physical layer operation, administration, and maintenance (PLOAM) cells.

As downstream frames are multicast to all ONTs from the OLT, only those cells addressed to an ONT are extracted by that ONT; the others are discarded. For upstream transmission, the OLT allocates cell slots to the ONTs. The OLT gives an ONT permission to send data by sending a grant via a downstream PLOAM cell. Although OLT-ONT distances vary, the OLT must receive the frames from the ONTs without frame collisions. To achieve this, the OLT mea-



□ Figure 3. The ranging method in ITU-T Recommendation G.983.1.

sures the distance to each ONT, and then tells the ONT to insert the appropriate delay so that all equivalent OLT-ONT distances are 20 km. This operation is called *ranging*.

Figure 3 shows the ranging method. To measure the round-trip delay between itself and each ONT, the OLT sends a ranging grant to each ONT and receives the ranging cell sent by the ONT in response. The OLT sets the ranging window on the upstream frame whose size is equivalent to 40 km of round-trip delay. It follows that the OLT can receive a ranging cell from any ONT that lies within 20 km of the OLT.

As the equivalent ONT-OLT distance is 20 km after the ranging operation, the phase difference between the downstream and upstream frames at the OLT is the round-trip delay corresponding to a round-trip distance of 40 km.

Due to the multicast nature of the PON, downstream cells are churned at the TC layer with a churning key sent upstream by the ONT. Churning provides the necessary function of data

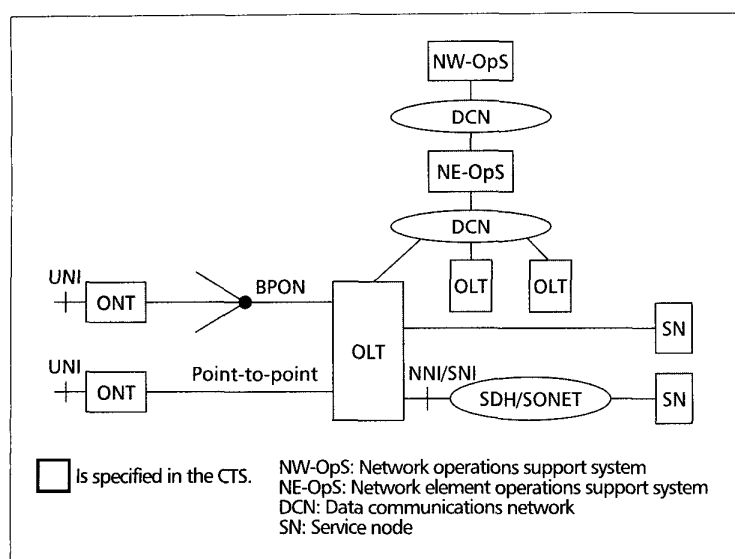


Figure 4. A B-PON system configuration example for CTS.

scrambling and offers a low level of protection for data confidentiality. The churning is performed for point to point downstream connections and churning can only be enabled or disabled per VP at its setup. The churning key is updated periodically with the value of the key provided by the individual ONT.

COMMON TECHNICAL SPECIFICATIONS

FSAN has successfully created the interface specification between the OLT and the ONT of the B-PON system, as described above. Equipment volumes will be higher and equipment costs lower if the number of different FSAN options adopted by network operators is minimized and commonality at the system level is achieved. NTT, BellSouth, BT, FT, and SBC have collaborated in developing the document of the CTS for the B-PON system. This document is available on the FSAN home page [1]. It lists each network operator requirement as:

- Required in 2001
- Required in 2002
- Required after 2002
- Not required

Figure 4 shows an example of a B-PON system configuration. OLTs are connected to digital service units (DSUs) via point-to-point¹ access lines and to ONTs² via B-PON access lines. The OLT is also connected to service nodes via transport lines directly, through synchronous digital hierarchy (SDH), synchronous optical network (SONET) transport networks or leased line transport networks.

The ONT provides customers with various user-network interfaces (UNIs): an asynchronous transfer mode (ATM) UNI for ATM services, a synchronous transfer mode (STM) UNI for circuit emulation services, and a 10Base-T/100Base-TX UNI for high-speed data services.

The network element operations support sys-

tem (NE-OpS) controls and surveys multiple OLTs, and ONTs and DSUs via the associated OLTs, and also provides the Q3, CORBA, or another interface to the network operations support system (NW-OpS). International standard or de facto standard interfaces will be used for B-PON and point-to-point access line interfaces, transport line interfaces (network node interface/service node interface, NNI/SNI), UNIs, and interfaces between NE-OpS and NW-OpS.

Despite the attempt to maximize the commonality and minimize differences, some differences are inevitable, due, for example, to existing service interfaces, power characteristics, and environmental conditions. The commonalities and differences are summarized in Table 1.

DEPLOYMENT STATUS

NTT, BellSouth, BT, FT, and SBC have deployed B-PON systems and are offering commercial services or plan to do so. This section describes the deployment status of each operator.

NTT

NTT's history of B-PON system development and deployment is shown in Fig. 5. NTT started with a 1996 field trial of a proprietary B-PON system [6]. This offered CATV, video on demand, and ISDN services to home users.

The ATM Link System was developed and used in a multimedia collaborative field trial [7]. This trial offered deterministic bit rate (DBR) virtual paths to business and small office/home office (SOHO) users.

The proprietary B-PON technology was combined with the ATM Link System in NTT's first commercial B-PON system deployment, which started in April 1997. This proprietary B-PON system offers ATM leased line services, the ATM Mega Link services, based on DBR virtual paths. The design reflects the experiences gained in the multimedia collaborative field trial. NTT has developed a succession of G.983-compliant B-PON systems since 1997. After a detailed laboratory test, they were introduced in June 1999. The system is a G.983-compliant, symmetric 155.52 Mb/s B-PON (class B and C); it supports ATM UNIs such as 155.52 Mb/s single-mode and multimode optical, 44.736 Mb/s coaxial, and 25 Mb/s UTP.

The growth in number of OLTs with the proprietary and G.983 B-PON interfaces is shown in Fig. 6. There are now more than 2000 G.983 OLTs installed all over Japan in 2001.

G.983 and the proprietary B-PON systems offer three types of ATM services: ATM Mega Link, ATM Share Link, and Mega Data Netz. ATM Mega Link offers DBR virtual paths. A newly developed virtual path protection switching mechanism is employed that offers three service classes: *dual* offers working and protection channels, both of which are DBR; *extra* offers bandwidth B using a main and sub channel in normal, but bandwidth B/2 in a failed main channel, since the main is switched over to the sub channel; and *single* has no protection channel. ATM Share Link offers GFR virtual channels with dual and single classes, while Mega Data Netz offers lower-bandwidth DBR and

¹ The DSU is out of the scope of the CTS:

² The ONT is a comprised of an Optical Network Unit (ONU) and a (or several) Network Termination(s) (NT).

Item	NTT	BellSouth	BT	FT	SBC
UNI	ATM25	ATM25 (later)	ATM25		ATM25 (later)
	DS-3	DS-1	E-1		DS-1
	STM-1	—	STM-1		DS-3 (later)
	10/100BASE-T (later)	10/100BASE-T	10/100BASE-T (later)	10/100BASE-T	10/100BASE-T
Access Line Interface (G.983.1,G.983.2, G983.3)	155.52 Mb/s symmetric WDM				
	Class C/B	Class C	Class B	Class C	
	12 bit VPI + 16 bit VCI field length				
Signaling for SVC	VB5.2(later)	VB5.2(later)	UNI 3.1(later)		UNI 3.1
	—	UNI 3.1	—		UNI 4.0
NNI Physical Layer	SDH	SONET	SDH, PDH		SONET, PDH
ATM Transfer Capability	DBR (Deterministic Bit Rate) SBR (Statistical Bit Rate) GFR (Guaranteed Frame Rate)				
ATM Cell Switching in OLT	Selectable duplicated or non-duplicated configuration Hitless switching in the duplicated configuration 600 Mb/s, more than 8 × 8 switch ports Point-to-point connection Point-to-multipoint connection VPI and VCI based cell multiplexing				
Clock function of OLT	±20 ppm accuracy of free run clock if no input clock Automatic hitless switching				
OAM Function	F4 (OLT and ONT) F5 (OLT)				
NE-OpS interface	Transported via an internal channel (ATM based channel) as well as an external channel (ISO/IEC 8802-3)				
Automatic control in OLT	Failure detection, system recovering, card switching and insertion				
UPC function	OLT			ONT, OLT(option)	OLT
Program replacement	Supporting program replacement in service and remote				
Maintenance	Hot swap and remote reset				
Environment	Temperature: 5–40°, Humidity: 5–85 percent (OLT)			ETSI300-019-2-3	the same as Bell-South, and so on
	Temperature: 0-40°, Humidity: 5–90 percent (ONT)				

Table 1. Overview of CTS.

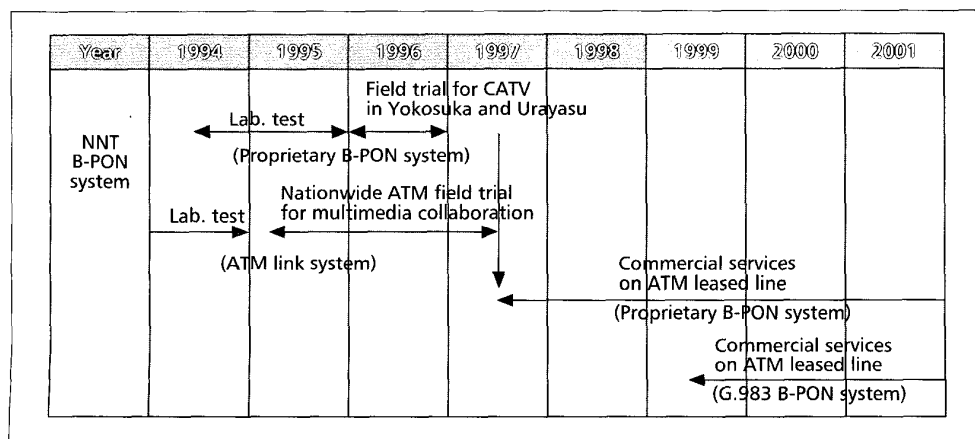


Figure 5. NTT history of B-PON system development and deployment.

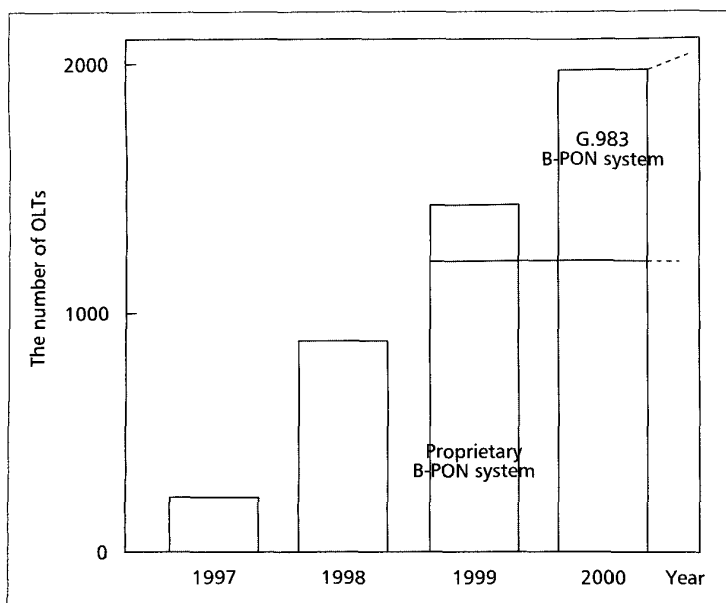


Figure 6. Growth of B-PON systems deployment.

GFR virtual channels with the dual class for closed user network services.

The total number of point-to-point circuits currently active in the ATM Mega Link, ATM Share Link, and Mega Data Netz services, offered over G.983-compliant systems as well as proprietary B-PON systems, was approximately 10,000 in 2000. At this time the proprietary B-PON circuits are in the majority. However, the number of G.983 B-PON system circuits is rapidly increasing to meet the IT demands for enlarged ATM services.

Looking to the future, the number of G.983 OLTs will increase with ATM service demand. Moreover, high-speed IP service will also be provided using a B-PON system. The system realizes upstream and downstream peak rates of 100 Mb/s for this service. It will use the dynamic bandwidth assignment mechanism being studied in FSAN and ITU-T Study Group 15. For these services, the USI will be 10/100Base-T.

BELLSOUTH

BellSouth turned up the first G.983.1-compliant B-PON fiber-to-the-home (FTTH) system in October 1999. The service, which offers video and high-speed data, was turned on to the first trial customers in November 1999 and then to the first retail customers in June 2000.

The FTTH first office application (FOA) service area contains approximately 400 homes. These homes are primarily served with aerial plant, but the area contains some buried plant as well.

The FOA implementation is a broadband overbuild, with telephone service continuing to be provided over existing copper pairs. The FOA architecture is shown in Fig. 7.

Two types of PONs are used in the FOA. The G.983.1 B-PON feeds an ONT that contains a 10/100BASE-T customer interface card for high-speed data services. A cascaded splitting architecture is used: a 1:8 splitter at the tradi-

tional remote terminal (RT) site and a 1:4 splitter at the curb or telephone pole. This configuration provides 32-way sharing of both the feeder fiber and the OLT ports.

The second PON feeds an analog video ONT to provide the BellSouth Americast entertainment video service set. The video PON is provided on a parallel fiber that has the same physical layout as the G.983.1 B-PON (32-way sharing using cascaded splitters). Together, the existing copper facilities and the two PONs provide a full set of residential services.

The bandwidth available on the B-PON is 155.52 Mb/s symmetrical shared across all users of the PON (maximum 32 customers). The PONs are aggregated at the OLT to a network interface and enter the existing BellSouth core data network. The FTTH FOA architecture supports BellSouth's residential FastAccess service set (1.5 Mb/s downstream/256 kb/s upstream). The 10/100 Ethernet interface is fed by an ATM permanent virtual channel (PVC). The PVC is provisioned to provide 1.5 Mb/s in the downstream direction and 256 kb/s in the upstream direction.

The Video PON provides analog video in the 50–550 MHz band and digital video in the 550–750 MHz band, making available approximately 80 analog video channels and 200 digital video channels to FTTH FOA customers. The analog portion of the offering can be fed directly into customers' existing television sets. The digital portion of the offering is provided through the use of a standard BellSouth Americast set-top box.

BellSouth's FTTH FOA provided valuable lessons that included:

- The experience gained by deploying fiber-to-the-curb (FTTC) systems that required the use of fiber in both the feeder plant and distribution plant has been directly applicable to FTTH. The FTTH FOA deployment would have been more challenging had BellSouth not had this experience.
- BellSouth's experience in providing broadband services on other platforms was directly transportable to the FTTH FOA platform. This included areas of marketing, definition of services, installation, and operations.
- Fiber handling in the field is critical. Handling includes items such as protection of fiber connectors, cleaning of fiber connectors and care in following installation parameters such as minimum bend radius of the fiber.

The next steps are to migrate video and telephone services to the B-PON in order to provide all services on a single fiber. The cost of digital set-top boxes such as those used for BellSouth's Americast entertainment video service is expected to continue to decline. Furthermore, digital enhancements including HDTV and the ability to associate Internet content with video content are expected to be highly valued by customers. Therefore, only digital video is expected to be required on the B-PON. G.983.3 is an update to the G.983.1 optical band plan and defines an enhancement band that is planned to be used by BellSouth for video.

As voice over IP (VoIP) matures, this service could be offered as part of the data stream on the B-PON, providing telephony to the end user.

Because G.983.1 is based on ATM cells crossing the access network, VoATM could also easily be offered on this architecture.

Another issue that must be dealt with for FTTH is powering. Historically, power for providing plain old telephone service (POTS) has been provided by the telco operator. Since the FTTH ONT is envisioned to be customer powered, lifeline telephony services must be addressed. At this time, the use of a battery to power the ONT in order to provide lifeline services in case of a power outage seems to be the most practical solution. The responsibility for battery maintenance would then be driven by ONT ownership (operator- or customer-owned). The question of ONT ownership is a business/regulatory question. Once the ownership question is answered, strategies for battery maintenance can be developed (customer responsibility, provided by the operator's technicians as part of basic service, provided as an additional service by the operator, send a replacement battery to the customer by mail, etc.).

Initially, FTTH will be deployed as a more cost-effective architecture for providing familiar voice, video, and data services. As FTTH becomes more widespread, new applications will emerge that will require the increased bandwidth.

BT

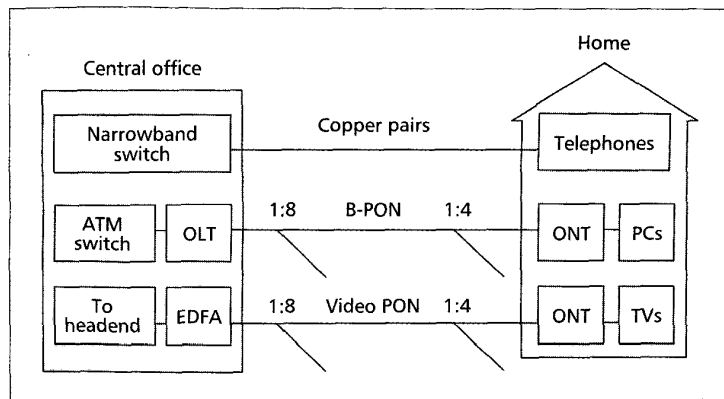
BT has not announced plans to deploy B-PON systems, although a trial of B-PON technology was conducted in Colchester as part of a wider trial of ADSL [8]. Following that trial, so far only ADSL has gone on to widespread deployment.

In the laboratories, BT is continuing to investigate the potential of B-PON and has maintained their interest in the CTS for possible application in the future BT network. BT's broadband customer needs are normally met with HDSL. Point-to-point fiber technology is used if the reach and capacity of HDSL is insufficient.

BT has experience in the deployment of narrowband PON. In this situation, volumes are low because demand can be met in most instances with traditional copper at lower cost. Although B-PON offers higher capacity, the number of customers requiring broadband service in a typical serving area of approximately 10 km radius is low and can be met more economically with point-to-point solutions. To achieve economies of scale, BT needs much higher demand for broadband services.

Green field deployment is an area of concern for BT. For incremental business development, volumes are too small to justify new technology such as B-PON. Higher volumes can be expected for green field FTTH. BT is looking to vendors to offer possible solutions in this area. If the technology arrives and is successful, BT may then be able to justify wider opportunities for deployment such as in areas of high broadband demand (now served with ADSL and HDSL) or where overhead lines need replacement.

As BT reported at NOC '99[5], B-PON has been considered for serving small-to-medium enterprises (SMEs). Some of the major conclusions from the analysis of the deployment economics were:



■ Figure 7. FTTH FOA architecture.

- B-PONs are most cost effective when used as a means of access, not as a means of Tier 3 switch bypass.
- Much of the cost savings of B-PONs relative to an SDH alternative come from reductions in the outside plant costs associated with remote placement of the B-PON splitters.
- Access fiber savings are independent of service type, bit rate, or circuit destination, but are very dependent on circuit volumes.
- B-PON deployment will not be justified on an incremental customer-by-customer basis. It must be planned, deployed, and the benefits actively sold.
- Meeting large anticipated access fiber demand using point-to-point fiber delivery would require massive e-side network restocking. It is very unlikely that this level of rebuild would be resourced. Even if limited to the business niche, considerable cost savings could accrue across all FSAN participants as a result of properly deploying a B-PON access network.

FT

In autumn 2000, FT launched its second RFP on FSAN B-PON technology for FTTOffice for business users. FT's requirements followed, of course, the CTS specification as far as the G.983 and the set of users' interfaces were concerned.

This RFP's aim was to more specifically address FT's current LAN connection solutions for data and voice services, in a more efficient way than previously achieved through the resource sharing capabilities of the FSAN technology. Additional applications such as the interconnection of mobile networks, connection of remote ADSL multiplexers or dedicated metropolitan rings are under study. The very first interfaces required were the Ethernet 10/100BASE-T, the circuit emulation E1 G.703 and the ATM STM-1 ones. In order to take full benefits of the B-PON technology, further FSAN standards such as Rec. G.983.dba that specifies dynamic bandwidth assignment for B-PON systems are planned in order to be able to match FT's full current service panel.

The FSAN technology optimization targeted by FT for the deployment planned by the beginning of 2002 also include the offer of local ser-

The extension of B-PON deployments to small business and residential customers is seen as a second step, when these customers demand for broadband services increases. At that time, the integration of existing narrowband services (POTS/ISDN) will be a target.

vices within the OLT, enabling the saving of backbone network resources, users' service integration at the ONT, and the offer of several service-level agreements depending on users' needs. Therefore, full optical path protection is required anticipating the finalization of Rec. G.983.sur that specifies survivability for B-PON systems.

FT is currently running a field trial that started at the beginning of September 2001 in Paris.

The extension of B-PON deployments to small business and residential customers is seen as a second step, when these customers demand for broadband services increases. At that time, the integration of existing narrowband services (POTS/ISDN) will be a target.

SBC

The B-PON systems SBC are planning to deploy for business and residential broadband access follow the existing G.983 series of Recommendations and are consistent with our CTS specifications. In addition, SBC is planning for enhanced B-PON systems meeting emerging ITU-T Recommendations that will add functionality, including enhanced survivability, dynamic bandwidth assignment, operations channel enhancements, and higher data rates. In addition, SBC will incorporate standards proceeding on management of B-PON systems, which will appear as an ITU-T Recommendation Q.834 series.

SBC has announced B-PON deployments as one of the next steps in broadband access [9]. SBC began a first customer application (FCA) of B-PON technology to small business locations in Houston, Texas, in May 2001. The B-PON system allowed DS1 services to be rolled from older copper infrastructure and carried on an all-fiber network, providing more reliable, expandable service to customers more efficiently. B-PON systems provide a cost-effective means to remove DS1 services from repeatered T1 systems that can interfere with DSL services in the copper plant. T1 rolls will be the initial phase of business PON deployments, which are projected to total nearly 1000 by year-end, expanding to nearly 9000 rolls in 2002. Future plans for the B-PON system include serving small businesses with Ethernet LAN services using 10/100BASE-T interfaces.

The assessment and development of B-PON FTTH systems is well underway in SBC [10]. Lab trials of the FTTH equipment are expected to begin in late 2001 or early 2002, and field trials are expected to begin several months later. Deployment of the B-PON FTTH systems will be targeted initially at "greenfield," or new-build, residential areas and retrofits of earlier FTTH/FTTC deployments. Indeed, SBC has already committed to one greenfield FTTH trial and deployment consisting of 6000 new residential units in San Francisco, California, which is scheduled to begin in 2002. Over 600,000 new living units are built each year in SBC's 13-state territory. While not all new-build units are targeted for B-PON FTTH (e.g., some are built in existing neighborhoods), many of these units may be appropriate for FTTH B-PON deployment. As the B-PON FTTH technology matures — and equipment costs decline — SBC can

consider retrofitting its copper-based access plant with FTTH, focusing on aerial-plant retrofits at first.

In the 13 states where SBC is the primary exchange operator, a significant percentage of new home developments are over 10 km from the office. As deployment distances increase, point-to-multipoint systems provide significant savings over point-to-point fiber access systems due to the sharing of fiber and office electronics. Further fiber infrastructure savings can be realized with single-fiber bidirectional systems instead of two-fiber systems leading SBC to target single fiber B-PON systems for both residential and business applications. SBC plans to deploy FTTH B-PON architectures meeting the specifications found in the newly approved G983.3. G983.3 allows for adding a wavelength for downstream video services over a single-fiber B-PON system already transporting bidirectional data and voice services. The cost reductions in optical technology coupled with the fiber cost savings from the B-PON architecture and driven by ever increasing bandwidth demand have motivated SBC to consider FTTH and FTTB as a practical technology choice for its future broadband access network.

CONCLUSION

This article briefly described the B-PON specification, initially developed by FSAN and formalized in ITU-T Recommendation G.983.1, to raise awareness of these specifications and the increased service potential promised by fiber access. The Common Technical Specifications, jointly developed by NTT, BellSouth, BT, FT, and SBC based on the ITU-T Recommendations, were also described to show how a number of operators have cooperated to minimize the cost of implementation by reducing the number of system variants needed. If profitable deployment can be justified, an increase in equipment volumes and a corresponding decrease in equipment costs can be expected, which will ultimately give very wide benefit. So far deployment volumes are relatively small; however, the prospects for the technology are very good.

NTT identified B-PON as the most cost-effective method to provide ATM leased line services for business users. NTT has installed more than 2000 G.983-compliant OLTs all over Japan, and the systems will increase in number, because the service demand continues to increase every year. BellSouth has successfully completed their first office application using a B-PON system to offer high-speed data services. BellSouth is currently conducting an economic analysis in preparation for deployment of FTTH and FTTB architectures in 2002–2003. FT is preparing to conduct a B-PON system field trial in September 2001 and will use it to provide high-speed data services in 2002. BT, having completed early trials, continues to test B-PON systems in the lab and is seeking solutions to the problem of providing cost-effective FTTH. SBC selected B-PON system as a prime candidate for its future access network. SBC

has completed lab tests for FTTBusiness and is planning them for FTTH. Deployment of FTTH and FTTBusiness is expected in the 2001–2002 timeframe.

REFERENCES

- [1] <http://www.fsanet.net>
- [2] ITU-T Rec. G.983.1, "Broadband Optical Access Systems Based on Passive Optical Networks (PON)."
- [3] ITU-T Rec. G.983.2, "The ONT Management and Control Interface Specification for ATM-PON."
- [4] ITU-T Rec. G.983.3, "A Broadband Optical Access System with Increased Service Capability by Wavelength Allocation."
- [5] D. Spears *et al.*, "Description of The Common Technical Specification for ATM PON System," NOC '99, June 23, 1999.
- [6] K. Terada *et al.*, "MPEG2-based Digital CATV and VOD System Using ATM-PON Architecture," *Proc. 1996 Int'l. Conf. Multimedia Comp. and Sys.*, 1996.
- [7] I. Tokizawa, H. Ueda, and K. Kikuchi, "ATM Transport System Architecture and Field Trial," *Proc. GLOBECOM '93*, Dec. 1993, pp.1449–53.
- [8] D. Faulkner *et al.*, "The Full Services Access Networks Initiative," *IEEE Commun. Mag.*, vol. 35, no.4, Apr. 1997, pp. 58–68.
- [9] R. Ireland, "Broadband Access," *Network+Interop*, May 9, 2001.
- [10] J. Erickson *et al.*, "FTTH Architectures and Systems SBC Requirements and Deployment Plans," OHAN/FSAN2001, Apr. 4–6, 2001, Yokohama, Japan.

BIOGRAPHIES

HIROMI UEDA [M] (hiromi@ansl.ntt.co.jp) heads Access Transport Systems Group, NTT Access Network Systems Laboratories. He joined NTT in 1977 and worked on R&D of digital signal processing, cross-connect systems, SDH systems, AND ATM systems. He is currently engaged in B-PON systems development. He received his B.S., M.S., and Ph.D. degrees from Tokyo Institute of Technology, Japan, in 1975, 1977, and 1993, respectively. He is a member of the IEICE.

KENJI OKADA [M] (okada@tiopat.com) is a patent attorney in the patent law firm in Japan. He chaired of FSAN OAN-WG, when he was a supervisor of NTT Access Network Service Systems Laboratories. He accumulated considerable experience in R&D of transmission systems. He received his B.E. and Ph.D. degrees in electrical engineering from Osaka University, Japan, in 1974 and 1986, respectively. He is a member of the IEICE of Japan.

BRIAN FORD [M] (brian.ford@bellsouth.com) is a senior member of technical staff in the Exploratory Development Group, BellSouth Science and Technology. He joined BellSouth in 1988 and has focused on broadband access technologies since 1995. He has led teams that deployed cable modem and ADSL architectures. Currently he is the manager in Exploratory Development for PON systems development. He represents BellSouth in FSAN and ITU-T. He is currently ITU-T editor for G.983.dba.

GLENN MAHONY [M] (glenn.mahony1@bridge.bellsouth.com) is a senior member technical staff in BellSouth's Science &

Technology organization. He has responsibility for fiber-to-the-business and fiber-to-the-home technologies, including the first field implementation of an FSAN-compliant BPON FTTH system. He has worked 22 years for BellSouth, primarily focused on advanced access technologies including the technical evaluation and approval of various lightwave and electronic technologies such as fiber to the curb. He has a B.S. degree from Clemson University.

STEPHEN HORNUG (steve.hornung@bt.com) heads the Network Technology Center in BTExact, providing technical expertise in core and access networks over fiber, copper, and wireless technologies. He graduated from Exeter with a B.Sc. in physics, and from Oxford with a D.Phil. in low temperature nuclear physics. He joined BT in 1979, working on optical fiber, cables, and plant. From 1998 he managed the Access Technology Centre, responsible for R&D in access technologies. He is a Fellow of the IEE.

DAVID FAULKNER [M] (dave.faulkner@bt.com) is BTExact's access technologies internal venture leader. His first degree in electrical engineering was at Bristol University in 1975. Both his M.Sc. in telecommunications systems and Ph.D. degree in electrical engineering were in collaboration with Essex University while working on the design of long-haul systems at BT Labs. From 1983 he pioneered both narrow and broadband passive optical networks. He is rapporteur for ITU/SG15/Q.2 on fiber access systems and chairs NOC.

JACQUES ABIVEN (jacques.abiven@francetelecom.com) leads R&D programs related to the evolution of broadband access technologies, architectures, and economical studies. He graduated from the ESE. He joined FT R&D in 1982. He acquired long experience on development of long distance copper and optical transmission systems. Then he participated in the definition and deployment of ISDN in France. He is now responsible for the deployment scenario and optimization of optical systems for business and professional customers. He leads the FT team in the FSAN OAN and deployment working groups.

SOPHIE DUREL (Sophie.durel@francetelecom.com) is project manager on Access Network Architecture at FTR&D. She received an M.S. Engr. in electronic and a doctorate degree in solid state physics from the University of Caen. She joined France Telecom in 1991 and has worked on video, advanced low-cost digital transmission, and access network architecture studies. She belongs to the France Telecom representation team in the FSAN group and is responsible for the operators' requirements for G983.sur.

RALPH BALLART [M] (rballart@tri.sbc.com) is VP, Broadband Infrastructure and Services, at SBC Technology Resources. His organization is responsible for broadband network element requirements and testing for SBC. He began his career with Bell Labs in 1980 and worked on SONET and other transport and switching projects while with Bellcore. He has a Ph.D. in physics from the University of Arizona.

JOHN ERICKSON [M] (erickson@tri.sbc.com) is director, Broadband Access and Video, at SBC Technology Resources. He received an M.S. Engr. from Cornell and a B.S. EE from Utah State. He worked at Bell Laboratories on photonic switching architectures. He joined SBC Technology Resources in 1989 and has worked in switching, access, and video. He participates in the FSAN group on the management committee and OAN Working Group. He acts as chair of the GPON transmission convergence subteam.