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From the Exploration-Programmes of Corporate Technology (2)

ATM passive optical networks for future fiber-based Access Networks

Description of Exploration Programme*

EP2, called "Residential Access & Services," is an exploration programme running in Swisscom for identifying the needs for the residential customer market segment after 2000. The programme encompasses the study of new technologies for the fixed Access Network, which will become important for Swisscom after 2000.

* Exploration Programmes are commissioned by the Swisscom Board of Directors and executed in Corporate Technology. The activities have a mean to long term time horizon (2–7 years) depending on the area.

ATM passive optical networks (APONs) are foreseen to be one of the most cost effective fiber-based solutions for broadband access networks. They allow a flexible bandwidth allocation to customers, and can be installed in different architectures, ranging from "fiber to the local exchange" to "fiber to the home," using the same type of equipment. APONs have been standardized by the FSAN GX consortium whose main goal was to group operators and vendors in order to generate high volumes, and thus, reduce the equipment costs. In addition, Swisscom Corporate Technology unit (CIT-CT) has conducted a laboratory trial with the APON system E-Flex 2000 from Broadband Technologies.

Introduction

The success of mobile telephony and Internet affect, on a large scale, the classical fixed access network (AN), which will have to play a different role in future. From a "single" service network dedicated to telephony, the AN will have to support higher bandwidth multiple services and will have to adapt to the individual demands of customers.

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The access network is the most valuable infrastructure of traditional telecommunication network operators (resulting from the privatisation of national companies) as it provides telecommunications on a national basis. In addition, a large part of the investments of a "national" operator are in the access network. The duration for renewing the access network is estimated to be between 30 and 50 years using a traditional amount of investment. The inherited access network infrastructure traditionally is copper (twisted pairs) and partially optical fibers in the feeder part. Although the future is clearly dedicated to optical fibers (due to broadband capability, EMC immunity, cable dimensions and possible distances), it is very expensive to replace the copper, at least in the "last mile". In addition, the trends of reducing the number of local exchanges lead to longer distances in the access network. Therefore, there is a need for new systems which permit a soft evolution towards an optical network, and which enable a short term amortisation.
These issues force the network operator to take special care of the investments in the access network. These investments must be as low as possible and future proof. This means that the solutions installed must be flexible enough to adapt to new situations (new services and/or new customers as well as new configurations like FTTLex, FTTCab, FTTC, FTTB or FTTH, see next paragraph). As this motivation is common to all "national" network operators, the Full Service Access Network Group of X operators (FSAN GX, see for example [1]) has been convened in order to specify a service independent system based on optical fibers which permits an efficient means to offer new broadband services. These common specifications shall permit the suppliers to reach a sufficiently large production volume (and an interesting market), in order to reduce costs adequately to start business. The efficiency of FSAN GX was so high that the specifications are now published by the ITU (G.983 [2]), and many suppliers have announced the development of such a product. Such systems, namely ATM passive optical networks (APON) will lead to a new generation of fixed access networks.
Although it does not make sense to install APONs that are non FSAN compliant, so far no supplier was able to provide a fully FSAN compliant system. At the same time, network operators must evaluate what the consequences of using FSAN APONs will be when commercially available:
- How to install the equipment in the existing network?
- What are the (potential) interconnection problems?
- How to use the new interfaces?
- How to transport the services?
- Are there consequences on services from using such a system?
- What are the exact functionalities and how to use/optimize them?

It is most important to have information on these issues in order to be able to plan the evolution of the network in an

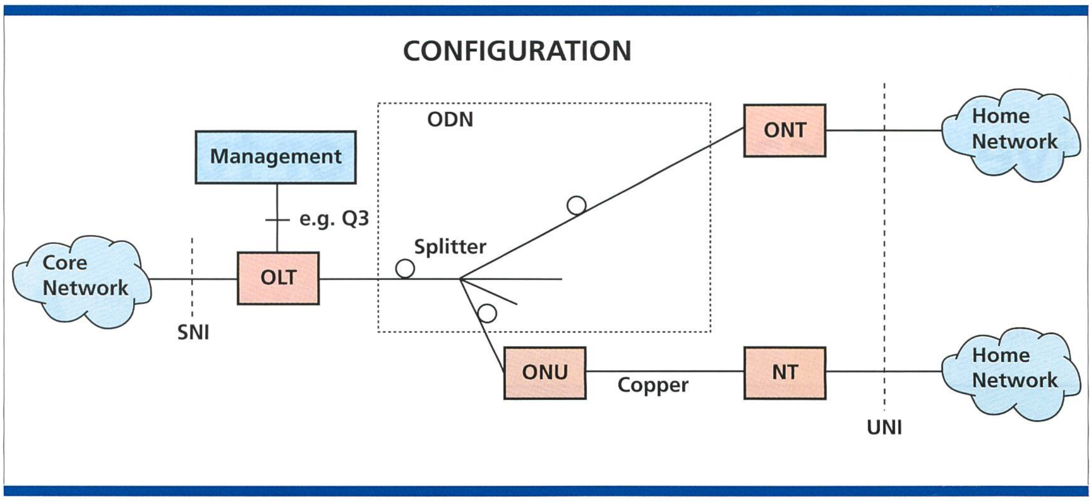

Fig. 1. Basic configuration of an APON.

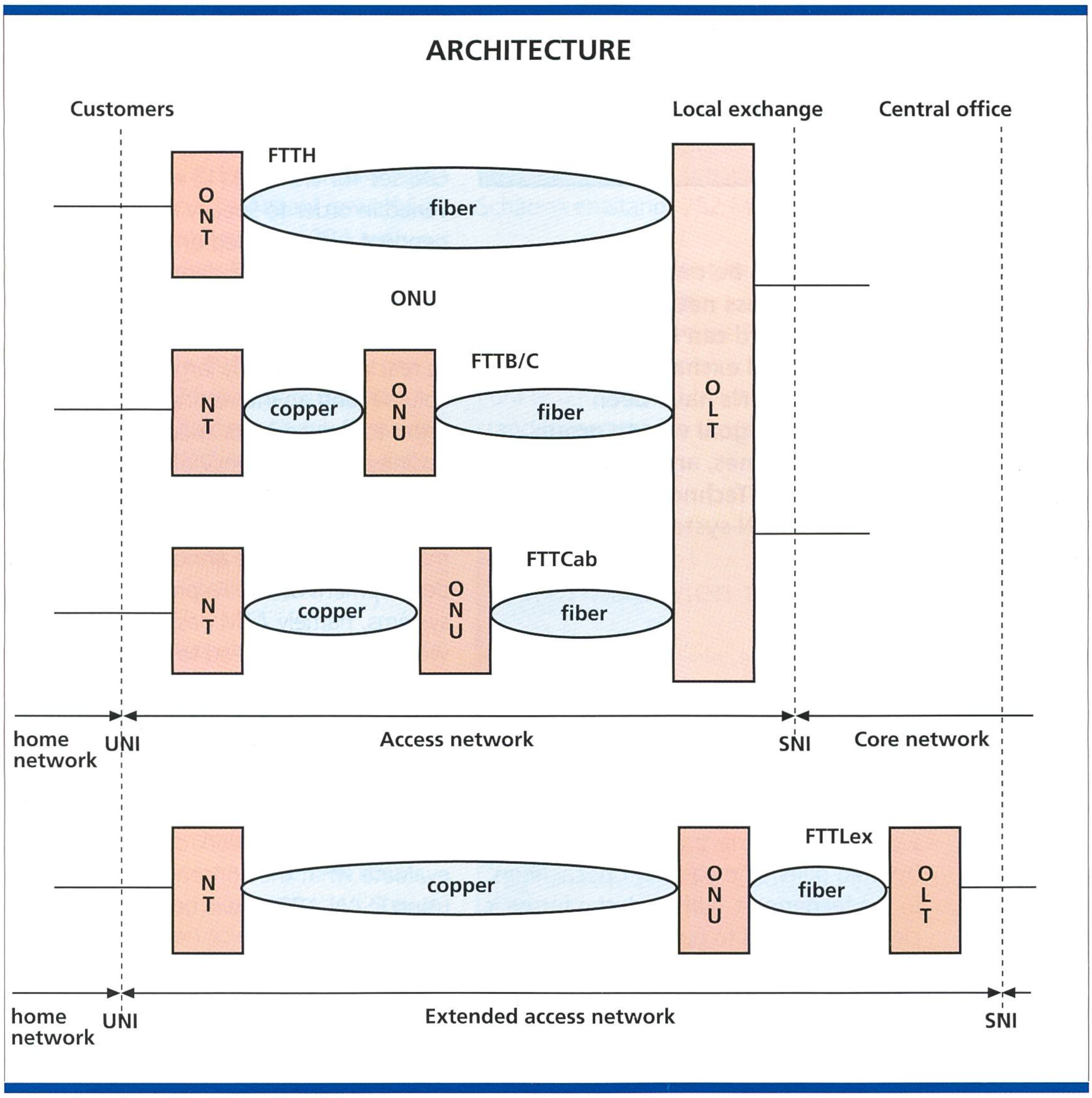

Fig. 2. Network Architecture using APONs.

efficient way. This was our motivation for installing a non-FSAN compliant APON system (combined with VDSL) in our laboratory in order to analyse its capabilities and evaluate the deployment problems. Further objectives were:

– To evaluate the remaining work to be done in order to have a full FSAN compliant system.
– To evaluate how easy it is to offer multimedia services with such a system.
– To expand the Full Service Laboratory of the Corporate Technology for future Swisscom related projects.

ATM PON

General description of the system

An ATM PON is a system mainly constituted of three parts, namely the OLT, ODN, and ONU, as represented in Figure 1. The ODN has the particularity of having one fiber passively split between

Abbreviations

General

AAL	ATM adaptation layer
ADSL	Asymmetric digital subscriber line
APON	ATM passive optical network
ATM	Asynchronous transfer mode
BAF	Broadband access facilities, RACE project on APONs
BBT	Broadband Technologies (equipment manufacturer)
CPE	Customer premises equipment
E1	2.048 Mb/s data signal
EMC	Electromagnetic compatibility
FMUX	Flexible multiplexer
FSAN GX	Full service access network, group X
FTTB	Fiber to the building
FTTC	Fiber to the curb
FTTCab	Fiber to the cabinet
FTTH	Fiber to the home
FTTLex	Fiber to the local exchange
FTTO	Fiber to the office
HDTV	High definition TV
IP	Internet protocol
ISDN	Integrated services digital network
ITU	International telecommunication union
LAN	Local area network
LANE	LAN emulation
MAC	Medium access control
MPEG	Moving pictures experts group
NT	Network termination
OAM	Operation and maintenance
ODN	Optical distribution network
OLT	Optical line termination
ONU	Optical network unit
ONT	Optical network termination
PAL	Phase alternation line
PDH	Plesiochronous digital hierarchy
PC	Personal computer
PCI	Peripheral component interconnect
PON	Passive optical network
POTS	Plain old telephony service
PMD	Physical medium dependent
PLOAM	Physical layer OAM
PVC	Permanent virtual connection
SDH	Synchronous digital hierarchy
SNI	Service node interface
STM(-N)	Synchronous transport module (-N)
SVC	Switched virtual connection
TC	Transmission convergence
TDM	Time division multiplexing
TDMA	Time division multiple access
UNI	User network interface
VAM	Video administration module
VC	Virtual circuit
VC-3	Virtual container 3
VDSL	Very high speed digital subscriber line
VIP	Video information provider
VP	Virtual path
VoD	Video on demand
WAN	Wide area network

Specific for BBT E-Flex 2000 system

OLT cards

ANI	ATM network interface
DBP	Digital broadcast processor
OLU	Optical line unit
SCP	Shelf control processor
TSP	Telephony signal processor

ONU cards

OCC	Optical common controller
TDIC	Telephony drop interface converter
VTR	Video transmitter/receiver

Management systems

CIT	Craft interface terminal
VAM	Video administration module

multiple ONUs, i.e. optical fibers in a point-multipoint architecture using a passive optical splitter. This passive splitting allows to share the optical transceiver in the OLT and its cost among many customers. The transport is based on ATM which allows, combined with the passive splitting, a very flexible and dynamic allocation of the bandwidth to the ONUs. However, special actions may be required with respect to privacy and security. Moreover, in the upstream direction a medium access control (MAC) protocol is required to avoid collisions. The ODN must comply with a certain set of specifications, e.g. in terms of maximum length between the OLT and ONUs, maximum splitting ratio, maximum power loss and wavelength that have to be used. The two directions for optical transmission in the ODN are identified as follows:

– downstream direction for signals traveling from the OLT to the ONUs;
– upstream direction for signals traveling from the ONUs to the OLT.

The OLT is the "head-end" of the PON system. It contains the interface functions to both the core network (SNI) and to the ODN, as well as the PON management, and other PON specific tasks such as ranging and MAC protocol. The management performs functions such as fault, performance, configuration, and bandwidth management. The ONU is located at each branch end of the optical network. It includes the interface functions to the ODN and interfaces to the customers (UNI), which support existing services (POTS, ISDN, leased lines, etc.) as well as broadband services. In case of the FTTCab/C architectures, the ONUs include xDSL functionalities (HDSL, ADSL, or VDSL) for the transport of ATM cells

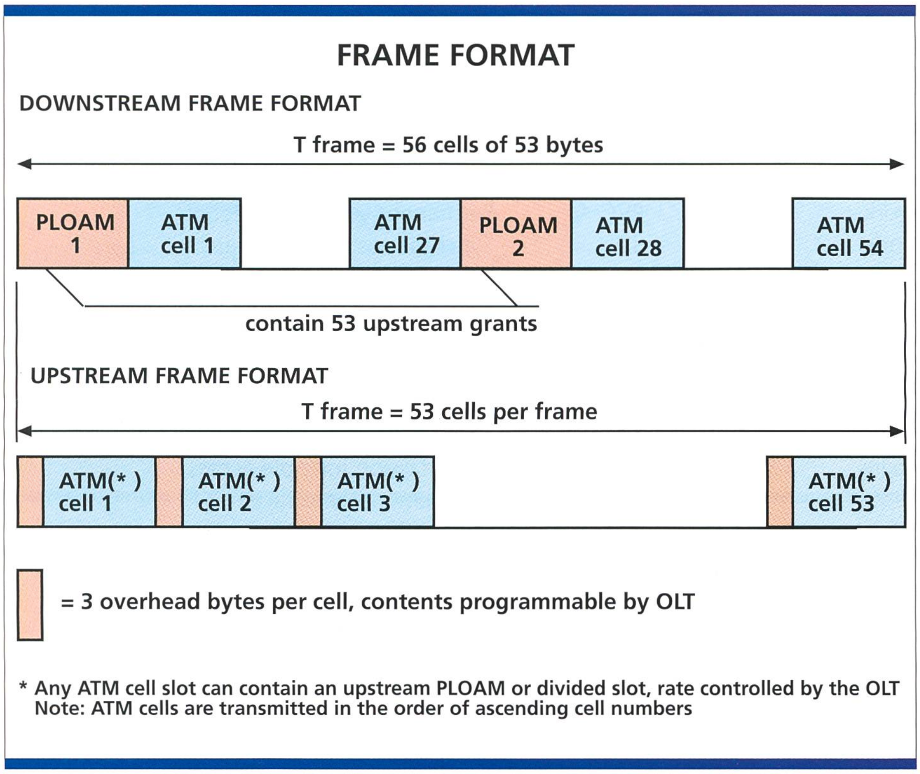

Fig. 3. Frame format for 155.52/155.52 Mbit/s PON.

on the copper drop. In this case, the interfaces to the customers are located in the NT (Figure 1).

Network architecture

The end point of the optical infrastructure in the AN is commonly used to describe the architectures. The "FTTx" terminology produces terms such as fiber to the local exchange/cabinet/curb/building/office/home (with corresponding acronyms FTTLex/FTTCab/FTTC/FTTB/FTTO/FTTH) representing implementations where the ONU is placed closer and closer to the customer premises.

Figure 2 shows examples of the considered architectures. The optical AN is common to all architectures, hence commonality in this system has the potential to generate large world-wide volumes. For existing ANs, the last drop to the customer premises represents the bottleneck in terms of bandwidth, and is the most sensitive cost component of any upgrade of the local loop infrastructure. FTTCab/C architectures make best reuse of the existing copper network, and in conjunction of xDSL technologies, eliminates the bottleneck problem. Thus, most of the operators see such architectures as a shorter term solution than that of an all fiber AN (FTTH).

FTTLex

This architecture will be used to interconnect today's local exchanges to the central offices. In this case, the ONUs will be located in the existing local exchanges and the OLT in the central offices. The PONs will be installed in parallel to existing SDH/PDH transmission lines. Eventually, spare fibers between exchanges may be reused. This scenario is a possibility to introduce APONs economically when the required bitrates in the access network can be transported via xDSL technologies, but when the capacity between local exchanges and central offices needs to be increased.

FTTCab/C/B Scenario

Within this scenario the following service categories were considered:

– Asymmetric broadband services (e.g., digital broadcast services, VoD, Internet, distant learning, telemedicine, etc.). Their capacity ranges from 2 up to 25 Mbit/s downstream and from 64 kbit/s up to 2 Mbit/s upstream.
– Symmetric broadband services (e.g., telecommunication services for small business customers, teleconsulting, etc.). Their capacity can span from 2 Mbit/s to at least 4 × 2 Mbit/s.
– PSTN and ISDN. The access network must be able to provide narrow-band telephone services in a flexible way (if no narrow-band services are provided, no extra cost due to these services will be generated, e.g. back-up battery for the ONU for higher service availability).

FTTH Scenario

Fiber to the Home service drivers are similar to those of the previous scenarios and are motivated by the following factors:

– There is no need for outdoor cabinet sites resulting in simpler network configuration and operation.
– No change of intermediate ONU is required to upgrade access network capabilities to accommodate future evolution of broadband and multimedia services.
– Maintenance is easy, because maintenance is required only for fiber systems, and fiber systems are regarded to be more reliable than hybrid fiber-metal ones.
– FTTH is a driver for the development of

Path layer			Refer to I.732 [11]
[3]Transmission medium layer Note: The transmission medium layer must provide the related OAM functions	TC layer	Adaptation	Refer to I.732
		PON transmission	Ranging Cell slot allocation Bandwidth allocation Privacy and security Frame alignment Burst synchronization Bit/byte synchronization
	Physical medium layer		E/O adaptation Wavelength division multiplexing Fiber connection

Table 1. Layered Structure of ATM-PON Network.

[3] Corresponds to the physical layer in the OSI model

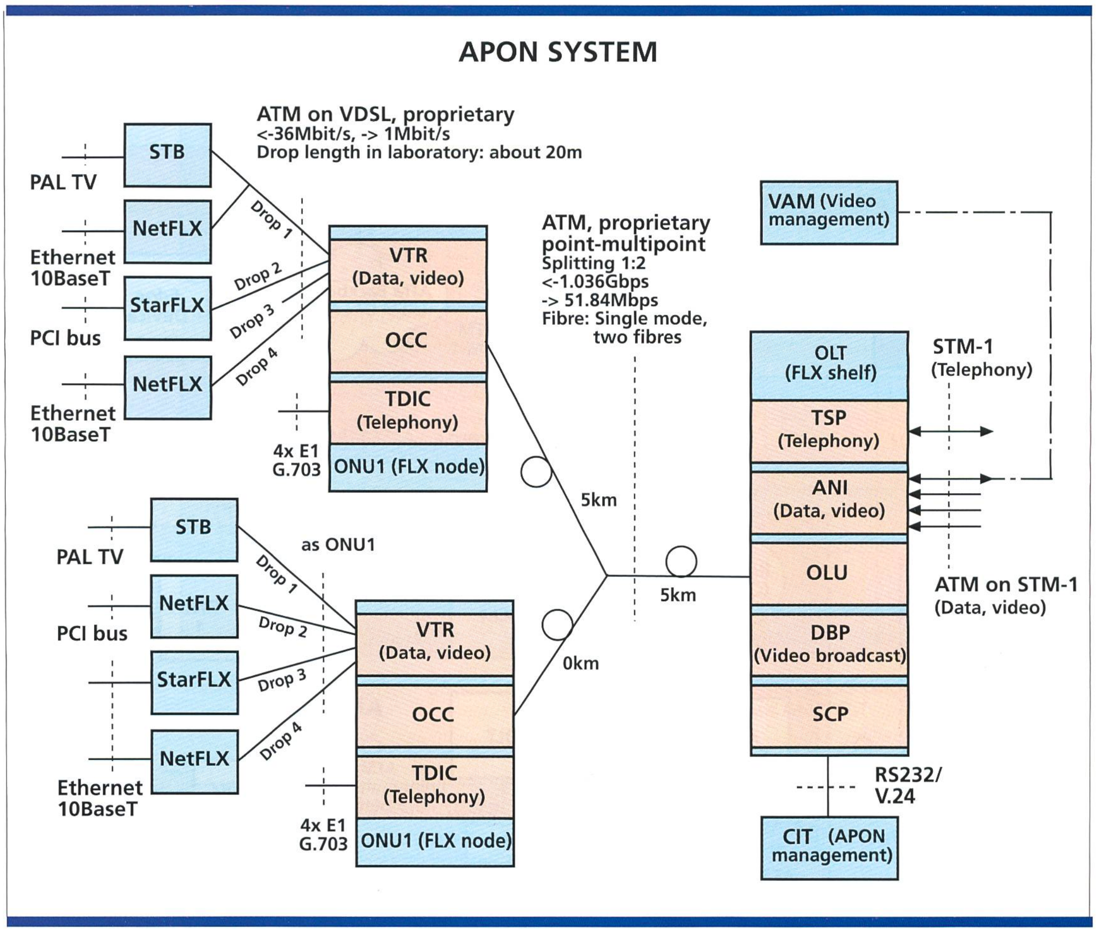

Fig. 4. Schematic representation of the APON system installed in the laboratory. The OLT (FLX shelf) and the two ONUs (FLX nodes) are shown with the cards they contain. VAM and CIT are used for the management of the APON. Eight broadband network terminations (set-top boxes, NetFLX modems or StarFLX NICs) are connected to the VDSL copper drops of the ONUs. Raw bitrates and distances in the laboratory for the ODN and raw maximum data rates in distances in the laboratory for the VDSL drops are shown. In addition, the interfaces to the core network at the OLT and to the customer equipment at the network terminations are shown.

advanced optoelectronics technologies. The greater the volume in production of optical modules, the faster the reduction in cost.

If these factors can be fully exploited they counterbalance a lightly higher per line cost. In that situation, the FTTH scenario is regarded as economically feasible even in the short term.

APON related activities

European research projects have been dealing with APONs for some time. In the RACE II project BAF (Broadband Access Facilities) [3], running from 1992 to 1995, it has been shown, that key technological issues of a high-speed APON, e.g. the dynamic bandwidth allocation, can be solved. In addition, an APON demonstrator system has been built. In the ACTS project BONAPARTE (Broadband Optical Network using ATM PON Access facilities in Realistic Telecommunications Environments) [4], running from 1995 until 1998, the APON system developed in the BAF project was enhanced and deployed in field trials with real small business users. The users worked with broadband services and multimedia telemedicine and teleteaching applications at different trial sites in Europe. The project Eurescom P614 with the title "Implementation strategies for advanced access networks" [5], running from 1996 until 1998, has considered the extensive range of available technologies for the access network, including APONs. The interfaces to the core network, different architectures, in particular FTTH enabling technologies, and techno-economic aspects have been studied.

APON standardisation

Forewords

The standardisation of APON systems in international standardisation bodies such as ITU or ETSI, results from the work of FSAN GX. All details of the PON physical interface can be found in the draft G.983 of ITU [2] and DTS/TM-03024 of ETSI [6]. Additional information on the interfaces, VDSL and APON can, in general, be found in the FSAN specification [1]. In this section, only the main characteristics are presented. Interested readers can refer to the above mentioned references for further information.

Layered structure of optical network

The APON system can be considered as a distributed access network operating on the VP sublayer of the B-ISDN protocol reference model (as described in recommendation I.321 [7]) by means of a passive optical distribution network. The protocol reference model is divided into physical medium, transmission convergence (TC), and path layer (G.902 [8], I.326 [9], G.982 [10]). The ATM-PON model is shown in Table 1. In the ATM-PON network, path layer corresponds to the VP of the ATM layer.
The TC layer corresponds to the transmission convergence sub-layer of the B-ISDN in I.321 and is divided into PON transmission and adaptation sublayers. The PON transmission sublayer terminates the required transmission function on the ODN. These functions are not seen from the adaptation sublayer.
The maximum bit rate supported by the APON as defined in G.983 is 622 Mbit/s downstream and 155 Mbit/s upstream.

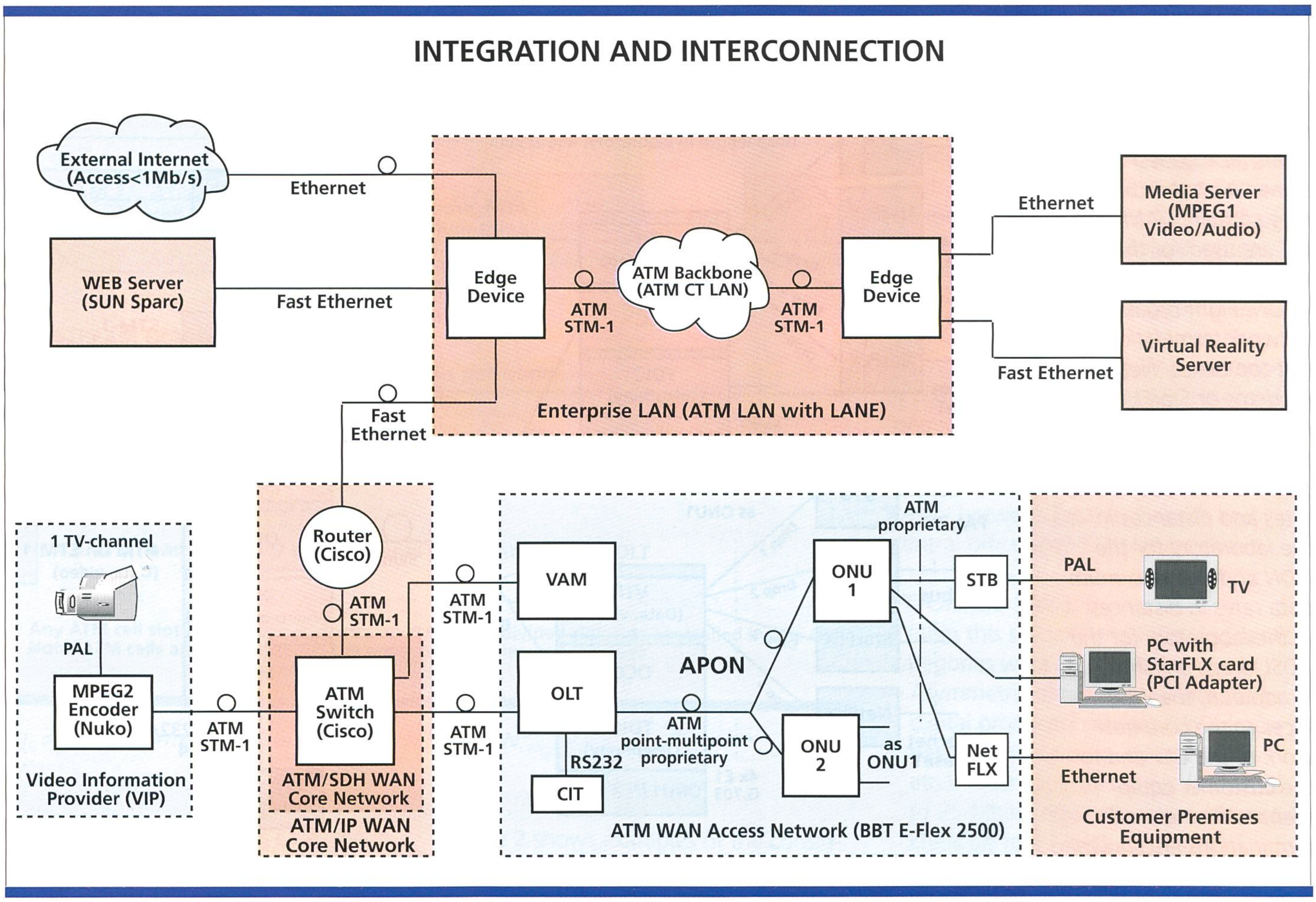

Fig. 5. APON integration and interconnection in the laboratory. The ATM/SDH WAN is represented in the laboratory by an ATM switch, the ATM/IP WAN by an ATM switch and a router. A video information provider is represented by a PAL TV channel and a MPEG2 encoder. The ATM based enterprise LAN can be interpreted as the LAN of a business customer, to which the PCs (residential customers) connected to the APON can set-up connections e.g. for teleworking.

Parameters	**Requirements**	
Fiber type	1.3 µm zero dispersion fiber (ITU-T G.652)	
Optical path loss	10-25 dB (ITU-T G.982 Class B) 15-30 dB (ITU-T G.982 Class C)	
Differential path loss	15 dB	
Maximum differential logical reach	20 km	
Maximum fiber distance	20 km	
Minimum supported split ratio	Restricted by path loss and ONU addressing limits PON with passive splitters (16-32 way split)	
Bi-directional transmission	1-fiber WDM (1.3 µm upstream, 1.5 µm downstream) or 2-fibers (1.3µm)	
Point-to-multipoint transmission	TDMA upstream TDM in downstream	
Nominal line hit-rates (Mbit/s)	*Donwstream*	*Upstream*
Option 1:		
Symmetric 155.52 (FTTCab/C/B/H)	155.52	155.52
Option 2:		
Asymmetric 622.08 (FTTCab/C/B)	622.08	155.52
Bit error rate (accross the entire PON)	less than 10^{-9}	

Table 2. Physical Medium Dependent requirements.

The time division multiple access (TDMA) technique is used for the upstream traffic transport. A medium access control (MAC) protocol is foreseen to resolve contention problems experienced when more than one ONU tries to make use of the common medium (upstream).

PMD layer

The physical media dependent (PMD) layer is fully standardized in G.983. Table 2 summarizes the main requirements of the ODN PMD layer.

TC layer

Introduction

The data are transported on the PON in the 48 bytes of the payload of the ATM cells. In the downstream direction all data are simply broadcast to all ONUs and only the data particularly addressed to an ONU can be used by this latter. However, the transmission in the upstream direction is far more complex since the medium is shared by multiple ONUs, which may result in collisions at the splitter. In order to solve this problem, a particular MAC protocol has to be used. Moreover, for an efficient use of the upstream bandwidth, a dynamic bandwidth allocation mechanism (as part of the MAC) has been suggested. All information needed for these mechanisms is carried in special cells called Physical Layer OAM (PLOAM) cells.

Frame structure
A particular frame structure was adopted in G.983. As an example, the frame structure for a symmetric PON is shown in Figure 3.
The downstream interface structure for both 155.52 Mb/s and 622.08 Mb/s consists of a continuous stream of time slots, each time slot containing 53 octets of an ATM cell or a PLOAM cell. Every 28 timeslots a PLOAM cell is inserted.
A downstream frame contains 2 such PLOAM cells and is 56 slots long for the 155 Mb/s downstream case. For the 622 Mb/s case, it contains 8 PLOAM cells and is 224 slots long.
In the upstream direction the frame contains 53 time slots of 56 bytes (one ATM cell + 3 bytes overhead). The OLT requests an ONU to transmit an ATM cell via grants[1] conveyed in downstream PLOAM cells. At a programmable rate, the OLT requests an ONU to transmit a PLOAM cell or a "divided_slot" (see next section). The upstream PLOAM rate depends on the required functionality contained in these PLOAM cells. The minimum PLOAM rate per ONU is one PLOAM cell every 100 ms.
Because the upstream cells come from different ONUs, the OLT has to resynchronize at the beginning of each cell. The information for doing this is contained in the 24 bits of the upstream overhead, divided as explained in Table 3.
The minimum guard time length is 4 bits. The guard time length, preamble pattern and delimiter pattern are programmable under the OLT's control. The content of these fields is defined by the "Upstream_overhead" message in the downstream PLOAM cells [2].

[1] In the APON context, grant has the meaning of "permit".
[2] A minislot is similar to an upstream time slot (3 bytes overhead + 53 bytes payload) but with a payload variable between 1 and 53 bytes.

Field	Purpose
Guard time	Provide enough distance between two consecutive cells or minislots to avoid collisions
Preamble	Extract the phase of the arriving cell or minislot relative to the local timing of the OLT, and/or acquire bit synchronization and amplitude recovery
Delimiter	A unique pattern indicating the start of the ATM cell or minislot, which can be used to perform byte synchronization.

Table 3. Upstream overhead bytes.

Parameter	BBT specification	Laboratory test
Maximum distance OLT-ONU	11 km (splitting ≤ 1:2) 7km (splitting ≤ 1:4)	10 km
Maximum splitting ratio	1:4 (distance OLT-ONU ≤ 7 km)	1:2
Maximum differential distance[4]	11 km/7km (equal to maximum distance OLT-ONU)	5 km

Table 4. Test of optical part.

[4] Differential distance. Difference between two distances ONU1-OLT and ONU2-OLT

Distance	Image quality for digital video distribution service		Throughput for TCP/IP data using RFC1483 with NetFLX and PVCs	
	Without splitting of VDSL drop	1:2 splitting of VDSL drop	Upstream	Downstream
20 m	ok	ok	1 Mbit/s (peak) 860 kbit/s (mean)	9,1 Mbit/s (peak) 8.3 Mbit/s (mean)
120 m	ok	ok	idem	idem
170 m	ok	bad	idem	8,2 Mbit/s (peak) 7 Mbit/s (mean)
220 m	bad	bad	idem	2,5 Mbit/s (peak) 2,0 Mbit/s (mean)

Table 5. Test of VDSL drop.

MAC protocol
PONs are by their very nature shared-medium networks. Thus, there needs to be some form of access protocol (the medium access or MAC protocol) that allows an ONU wishing to transmit upstream to do so without causing any interference to the data transmitted by other ONUs. In the downstream direction, the data are broadcast to all ONUs from one OLT, and no MAC is needed.
In the APONs, the principle of the MAC protocol can be simply described as follows. The OLT (where the MAC resides) sends a grant to an ONU for access on the upstream fiber. Each grant allows one and only one ONU to send one upstream cell in a time slot. For an efficient use of the upstream bandwidth (dynamic bandwidth allocation), the MAC must be informed on the state of the traffic at each queues of the ONUs, and then distributes grants accordingly.
All information needed for the MAC protocol is carried by the PLOAM cells. In the downstream direction, they are filled with 27 grants (the rest being used for messages). The information on the ONU queues' status is carried upstream by a special kind of PLOAM cell called divided_slot. A divided_slot occupies a complete upstream time slot and contains a number of minislots[2] from a set of ONUs. For example, one divided_slot can contain 8 minislots of 7 bytes (3 bytes overhead + 4 bytes payload). In this case, 8 ONUs can transmit their queues status in one upstream time slot thus allowing a faster reaction on changing upstream traffic.

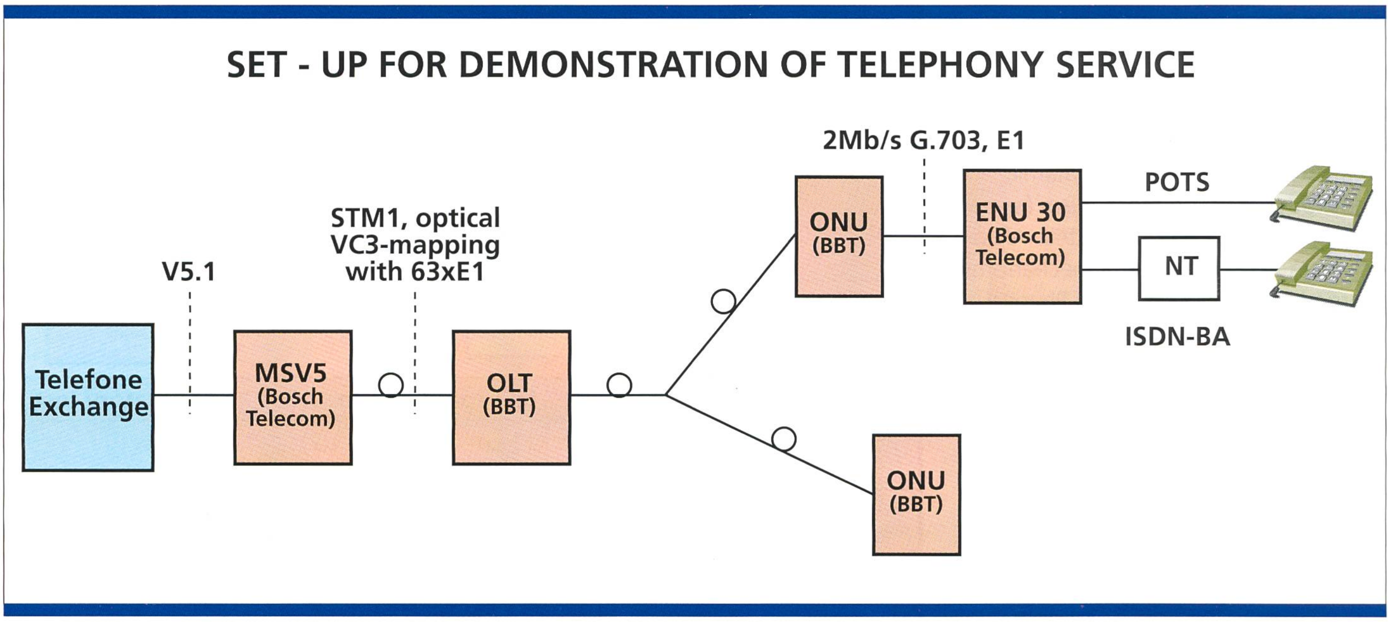

Fig. 6. Set-up for the demonstration of telephony service in the laboratory with multiplexing equipment available from Bosch Telecom. The STM1 signal at the OLT is demultiplexed to a V5.1 signal by the MSV5 multiplexer which can be connected to the telephone exchange. On the ONU side, the ENU30 multiplexer, to which the telephones and ISDN network terminations (NTs) can be connected, demultiplexes the E1 G.703 signal to POTS and ISDN-BA signals.

Ranging

In the upstream direction each ONU has to transmit in the right time slot to prevent collision of bursts and corruption of data. It has to be pointed out that each ONU cannot "sense" the presence of an upstream data packet transmitted by another ONU, so the synchronisation has to be achieved by sending downstream the proper timing signals.
The different distances between OLT and ONUs have a twofold effect:
- timing commands sent by the OLT are received at different moments by the ONUs
- packets sent by the different ONUs experience a different propagation delay before reaching the OLT.

The solution is to insert an equalising extra delay so that for all the ONUs the global round trip delay is always equal to a fixed system parameter (which is the maximum permitted round trip delay).
In G.983, a full digital in-band based ranging method is used by the PON system to measure the logical reach distances between each ONU and the OLT. The maximum range of the PON is at least 20 km. The transmission delay measurement for each ONU is performed whilst the PON is in-service without disrupting service to other ONUs. Additional information can be found in [2].

APON laboratory trial

APON evaluation and description

A Call for Tender was sent in September 1997 to 11 potential APON suppliers for the delivery of a system to our laboratory by the end of 1997. Broadband Technologies (BBT) and Bosch Telecom made a common tender, and were the only ones able to respect the deadline. The quality of the technical description as well as references of commercial and laboratory applications were additional arguments to choose their APON system called E-Flex 2500.
The system installed in our laboratory is shown in Figure 4. The OLT is connected to the ATM core network by STM-1 interfaces for video and data traffic (ANI card), and by an STM-1 interface for telephony (TSP card). The PON, which connects the OLT to the two ONUs, uses a proprietary point-multipoint protocol with a raw bitrate of 1.036 Gbit/s downstream and 51.84 Mbit/s upstream. Each ONU contains a card with four VDSL interfaces for broadband services on copper twisted pairs (VTR card). A raw data rate of 36 Mbit/s downstream and 1 Mbit/s upstream is possible on each drop. Three types of Network Terminals (NTs) can be connected to a VDSL drop: a set-top box, a NT with an Ethernet 10 base-T interface (NetFLX) or a PC NIC (Network Interface Card) StarFLX. The set-top box is used for switched digital video broadcast services (digital TV distribution) and is connected to a standard TV set. The NetFLX modem and the StarFLX card are used for IP based high-speed interactive data services with a PC as terminal equipment. For telephony service, the ONUs have G.703 [12] E1 interfaces.
The management system consists of two parts. The Video Administration Module (VAM), running on a Sun workstation, allows to manage the switched digital video broadcast services. An example is the provisioning of the desired TV channels to the subscribers. The Craft Interface Terminal (CIT), running on a PC, is used for the management functions of the PON itself, e.g. to retrieve alarms, provision data channels, or add, edit, and delete cards in the OLT or ONUs.

BBT APON integration in the laboratory

The BBT APON was integrated in the experimental broadband platform of the Corporate Technology department, called Full Service Lab (FS-Lab). For the interconnection to the existing FS-Lab, and to demonstrate and study the transport capabilities of the APON, additional equipment was installed: an ATM switch, a router, a MPEG2 encoder, set-top boxes and terminal equipment (PCs). The

interconnection of the APON with these devices is shown in Figure 5. This configuration allows the transport and demonstration of digital broadcast services and high-speed interactive data services.
For digital broadcast services, the APON will be connected to an ATM/SDH core network in real use, represented in the laboratory by the ATM switch. Video Information Providers, represented by a TV channel and the MPEG2 encoder in the laboratory, can send their channels through the ATM core and access network to the customers.
For IP-based data services, the APON will be connected to a IP/ATM core network in real use, represented in the laboratory by an ATM switch and a router. The IP/ATM laboratory core network has been connected to an ATM enterprise LAN, which was set up in the FS-lab project. The enterprise LAN is based on LANE and connected to several servers and to the Internet.

Services and applications

Switched digital video broadcast services
Without compression, a digitally coded PAL video signal would generate bitrates as high as 250 Mbit/s. Thus, compression techniques that reduce the temporal and spatial redundancies contained in the video signals were developed in MPEG. With the MPEG2 standard [13], the bitrates can be reduced to typical values of 4 to 6 Mbit/s at PAL quality. This allows, for example, to transmit a few digital MPEG2 channels per customer on an APON. Higher quality could be reached for higher bitrates, e.g. HDTV at 15 Mbit/s.
The Nuko encoder used in the laboratory allows digital MPEG2 coding of one video signal at bitrates ranging from 2 Mbit/s to 12 Mbit/s. In addition, it contains the mapping function to ATM using ATM adaptation layer 5. In the ATM switch, one PVC per video channel is necessary for the transport to the OLT. For the configuration and management of channels, subscribers, and Video Information Providers in the APON, both the CIT and the VAM (Figure 5 and Figure 6) are necessary. The set-top box contains the inverse functions of the encoder: it extracts the MPEG2 signal from the ATM stream and converts it back to an analogue PAL signal that can be displayed on a TV set.
One OLT of the BBT APON system can support up to 384 different digital video channels, streaming from a maximum number of 8 VIPs. Each customer requesting a particular channel sends a signal to the OLT which puts a copy of this channel on the PON. This simple mechanism has the drawback of duplicating the same channel and of sending it simultaneously on the PON, as many times as requested by different customers. The number of channels simultaneously watched by all customers is only limited by the capacity of the PON. Systems with more efficient use of the bandwidth allowing a single copy of a channel on the PON are still being discussed within FSAN and planned for the future.
In the laboratory we have realized and demonstrated the distribution of one TV channel. Based on a qualitative visual image check, analogue TV quality is reached for bitrates of at least 4 Mbit/s.

IP based high-speed interactive data services
Two types of IP-based data services have been configured in the laboratory, both using ATM cells for the transport in the network, but different methods of mapping the IP data into ATM cells. The NetFLX modems use RFC1483 [14], sometimes called "Bridging", and ATM PVCs. The StarFLX cards use RFC1577 [15] also called "Classical IP over ATM," and ATM SVCs. The former method is running

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Zusammenfassung

Passive optische ATM-Netzwerke (APON) für zukünftige Glasfaser-Zugangsnetze

Passive optische ATM-Netzwerke (ATM passive optical networks, APONs) gelten derzeit als eine der kostengünstigsten Glasfaserlösungen für Breitband-Zugangsnetze. Sie ermöglichen flexible Bandbreitenzuteilung für die Kunden und können unter Verwendung gleichartiger Anlagen in verschiedenen Architekturen installiert werden (von Glasfaser bis Local Exchange ebenso wie von Glasfaser bis ins Haus).

Für APONs wurde durch das Konsortium FSAN GX ein gemeinsamer Standard festgelegt, der das Ziel verfolgt, durch Einbeziehung der Betreiber und der Verkäufer hohe Stückzahlen zu ermöglichen, welche dann wiederum die Preise der Anlagen niedrig halten sollen. Der neue Standard beschreibt im wesentlichen die vom Medium abhängigen physischen Anforderungen, die Anforderungen an Übertragungskonvergenz sowie Ranging-Aspekte. Der neue Standard ist Teil der bestehenden Standards ITU und ETSI.

Die Swisscom Corporate Technology Unit (CIT-CT) hat nun einen Laborversuch mit dem APON-System E-Flex 2000 von Broadband Technologies unternommen. Für die Endleitung zum Kunden wird hier kupferbasierte VDSL-Technologie eingesetzt. Spezifizierte Kapazität: Bis zu 36 Mbit/s pro Kunde bei maximalen Längen der Endleitungen von 270 Metern.

Im Labor wurden Ausstrahlung von Digitalvideo (MPEG-2) und interaktive IP-basierte Hochgeschwindigkeits-Datendienste eingerichtet und demonstriert. Zudem wurde auch die Leistungsfähigkeit der optischen und der VDSL-Bestandteile des APON-Systems geprüft.

Im Laborversuch konnten Installation und Management von APON ebenso eingeübt werden wie die Integration des Systems in eine reale Umgebung für kommerzielle Nutzung. Es besteht nun Klarheit über die Funktionsanforderungen an das System für den Transport von Digitalvideo und IP über ATM.

stable in the laboratory. However, the use of the latest software version in the router (Cisco) was crucial. The latter method is basically running, too, but the stability needs to be improved.
A PC connected to the APON by either method can establish a data connection at the IP-layer to any other PC connected to the APON, to any server connected to the enterprise network, or to the external Internet. The necessary functionality and involved layers in the APON, the ATM switch and the router for the data transport depend on the mapping method of IP data into ATM cells on both endpoints of the connection. These aspects have been clarified in the laboratory trial [16].
The maximum raw data rate to a PC connected to the APON for TCP/IP data is 10 Mbit/s downstream and 1 Mbit/s upstream (the downstream raw data rate on a copper drop is higher (36 Mbit/s), but can be split to up to 6 PCs).
Several applications have been set-up in the laboratory in order to demonstrate the capabilities of the APON and the network: Fast Internet access, MPEG-1 video (on demand), desk-top videoconferencing, audio on demand, and teleshopping using VRML. In addition, the experience gained can be applied to teleworking as an example of an application: The PCs connected to the APON can represent teleworking places in real business use, which need connections to the enterprise network (ATM LAN).
The most demanding application in terms of bandwidth is video. Good quality video on the PCs was obtained, when coded at 1.3 Mbit/s (MPEG1 coding). Thus, the data rates possible with the APON are more than sufficient to support all the installed applications. The 10 Mbit/s downstream capacity would allow today's Internet to evolve to a truly multimedia Internet. The capacity will be sufficient to satisfy the needs of mainly residential customers for a while.

Telephony service
Analogue telephony and ISDN basic access can be transported using the BBT APON, but additional equipment is necessary for the interconnection to the telephone exchange and to the telephones. The G.703 E1 interface at the ONU needs to be demultiplexed for interconnecting telephones, and the STM1 interface with mapped E1-channels at the OLT for interconnecting the telephone exchange. Equipment for the demultiplexing is available from Bosch Telecom, and would be interconnected to the APON as shown in Figure 6. Another variant, which could be tested, would be to use SDH and PDH multiplexing equipment used in today's network of Swisscom. As SDH and PDH interconnection techniques are very well known in Swisscom's operational departments, telephony service has not been realized in the laboratory, as it would not create new know-how for Swisscom. However, tests are necessary before a potential commercial use of the BBT APON system.

Laboratory tests
Optical part
The optical part of the APON was tested by carrying through a set of experiments with the parameters listed in Table 4, in comparison to the ones specified by BBT. No particular mismatches were observed thus suggesting that the optical part, up to the values specified by BBT, would be ready for commercial use. However, The whole ODN of the BBT system would have to be changed in order to achieve FSAN compliance, especially regarding the splitting ratio and distances.

VDSL part
The VDSL part was tested by checking the image quality of the digital video distribution service and by throughput measurements for the IP-based data services for different drop distances. The main results are shown in Table 5. BBT specifies a maximum drop distance of 276 m for category 5 twisted pair cable. The VDSL drop can be split using twisted pair to coaxial converters and coaxial splitters up to a ratio of 1:6, which decreases the achievable distances due

to the attenuation in the splitter. The twisted pair cable of our Access Network is typically of lower quality than category 5. In order to simulate a real access network situation, similar cable was used in the laboratory. The results in Table 5 show that the necessary service quality can only be obtained up to 120 m drop distance. This distance needs to be improved for use in the field. Moreover, copper distribution points may result in a loss of transmission quality due to EMC problems. BBT has announced an improved VDSL version for the beginning of 1999.

Conclusions

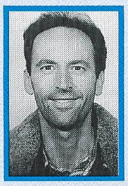
APONs have been successfully standardized in the international FSAN consortium. The standardisation has been followed by the Corporate Technology department and is in line with Swisscom's requirements, as far as these requirements can be foreseen today. The APON FSAN standard has been integrated in ITU and ETSI draft standards which are planned to be approved in 1998. Systems compliant with the standards should become available in 1999/2000. The production of high volumes of standardized APONs suitable for many Network Operators will generate systems at lower prices. Thus, APONs are a promising alternative to upgrade the access network with optical fibre: in situations, where copper cannot deliver the required bandwidth, or in greenfield areas, where new investments must be made.

The laboratory trial allowed to get a realistic picture of the state and capabilities of commercially available APONs. The BBT APON system is in a good state to be used in the laboratory, and supports digital video distribution, high-speed interactive IP data services and telephony. With an improved VDSL part, the system could be tested in a field trial with real customers.

In addition, the laboratory trial has resulted in important technical competence and experience in the field of APONs. Firstly, it became clear, how the BBT APON can be integrated and interconnected to a larger network, which functionality is necessary inside and outside of the APON, and which services can be delivered using APONs. For digital video distribution, skills were developed on how to configure and manage the necessary equipment for commercial use of the service. For interactive IP-based data services, the functionality of the equipment required to transport IP over ATM, including the interworking of different encapsulation methods and protocols (ATM, IP, Ethernet), has been identified. In addition, applications which might be transported by APONs have been identified.

This competence allowed us to participate as credible partners in the international FSAN standardisation. In addition, it will support the efficient introduction of APONs for commercial use in Swisscom.

As soon as FSAN compliant equipment will become available, further laboratory tests and a field trial should be carried through, in order to define Swisscom's strategy for the commercial introduction of APONs. 9.4



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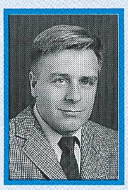

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