IP/ATM Integrated Services over Broadband Access Copper Technologies

†Arturo Azcorra, *Enrique J. Hernández-Valencia, ‡Julio Berrocal, †David Larrabeiti

†Área de Telemática, U. Carlos III de Madrid ‡Dpto. Ingeniería Telemática, UPM

**Bell Laboratories, Lucent Technologies*

Abstract

A rich set of broadband access copper technologies is available in the market today, and more are coming out of the laboratories, rapidly moving to standardization. The most likely future scenario will be one where many different technologies will coexist. This multi-access-technology paradigm poses an interesting internetworking problem where interoperability, capability to support today's and next future's user services play a major role in the design of a network architecture. This paper begins with an overview of current and new xDSL access technologies to continue describing an access network design that harmonizes the interconnection between PON, xDSL and native ATM transport technologies. The usage of ATM technology for the interface to the broadband access and transport networks is then presented and justified. The paper continues studying the protocol architectures proposed for access to Network Service Providers, considered a driver application for broadband access deployment. Finally, different protocol architectures that can provide integrated services support at the user equipment are analyzed.

Keywords: Broadband access technologies, Integrated Services Internet, RSVP, ATM, xDSL, broadband services.

1 Introduction

Multiple technologies are being developed to provide high-speed access to small office and residential users. Digital Subscriber Line (DSL), Hybrid fiber coaxial systems (HFC), several forms of passive optical networks (PON), fixed wireless local loop (WLL), various types of radio frequency multipoint distribution systems (xMDS), and satellite communication at different earth orbits (xEO) are being developed to serve this emerging market need. Several studies [1,2] show that none of them appears to be dominant under a techno-economic criterion, and for this reason the infrastructure actually deployed will consist of a mix of the different technologies. The advantages of DSL are clear for network operators: it makes use of the existing twisted pair infrastructure, its cost model is lineal for each new subscriber, it requires minimal upgrade to the feeder plant, it can be multiplexed in the distribution plant and it provides per-user dedicated bandwidth.

The network model to provide broadband residential services over xDSL is shown in Fig. 1 [4,6]. This network model is the same, at this level of abstraction, as the one used for HFC access networks. The model assumes that small office and residential users have one (or possibly several, one for each specific service) Subscriber's Premises Network (SPN) connecting every communication terminal device (TV, PC, telephone, fax, etc.). The SPN is connected to a User Access device (UA) that interfaces to the broadband access network. Subscribers use the access network to reach Service Nodes, where content servers, toll gates, service gateways and switches are located. Service Nodes can be connected directly to the access network by means of a Service Access device (SA). It is also possible to have remote Service Nodes accessible through an intermediate Transport Network connected to the broadband access network through a Transport Access (TA) device.

Concrete instances of UA devices are set-top boxes, cable modems for CATV access networks and xDSL modems. UA devices today are service-specific (POTS, ISDN, TV, Internet access,...) and access-network-specific. Consequently, for each combination of a service and an access network technology it is required to design and deploy a different device. The same applies to SA devices, but the situation of TA devices is somehow different. This is so because ATM is largely dominant as transport technology, and therefore it is only required to design a specific device that provides an ATM interface for each different access network technology, when this transport interconnection is needed.

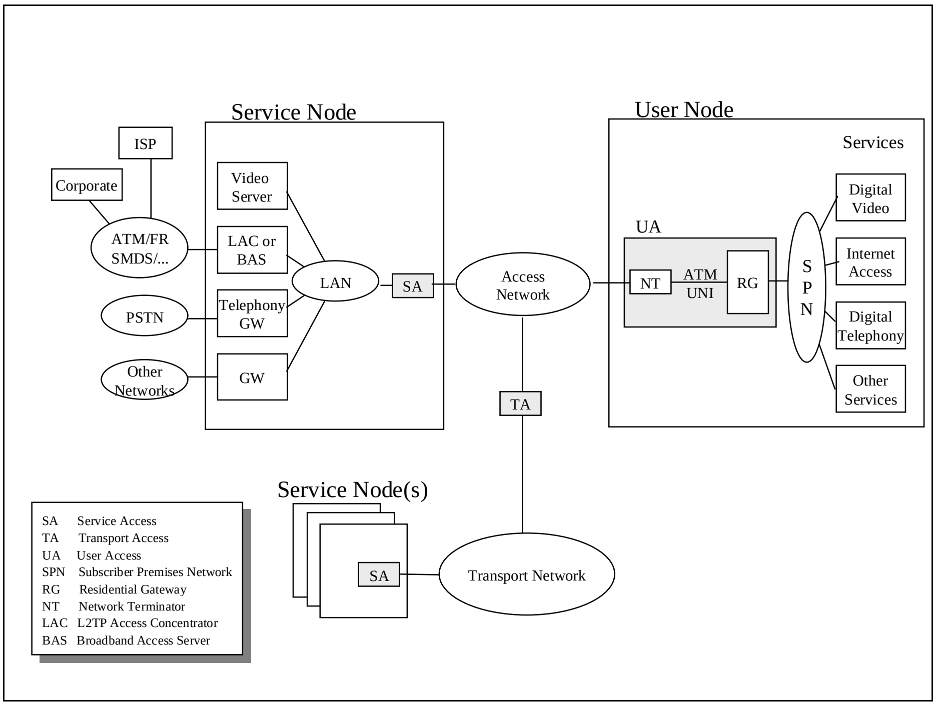

Figure 1 Network Model

A relevant example of a service and an access network that conform to the previous structure is high speed Internet Access. Several Internet Service Providers (ISPs) are delivering xDSL service today in the U.S. using dry copper. Others are using in-building copper in large office and apartment buildings to offer xDSL access speeds to small businesses or residents. With increasing competition for local service, embedded service suppliers are looking for ways to creating new services from the existing plant by offering value-added services. There are two different market segments being targeted: the single user home office/residential user and small or branch offices with multiple users (also referred collectively as the Small-Office/Home-Office market – SOHO). Packet-based solutions are appropriate when emphasis is on improved response for Internet access, general Web browsing, and connection to IP-based corporate intranets on a best-effort basis. Link layer protocols like PPP can run over xDSL as easily as an analog modem.

Some services to be provided over broadband access are video servers, packet telephone, videoconference, Internet access, network games and computer supported cooperative work [7]. These services require the transmission of digitized, compressed and packetized streams of multimedia traffic with multipoint-to-multipoint (in the general case) transfer capabilities. Quasi-isochronous transmission is mandatory for interactive multimedia services, whereas for non-interactive ones a higher delay jitter may be tolerated. As some of the applications generate a variable bit rate stream, it is required an underlying technology capable of providing quality of service (QoS) transport for traffic sources with statistical characterization.

Legacy services provided by copper access technologies will retain their role. These service modes are not addressed in this paper, and are not depicted in Fig. 1. The broadband services (that may include phone and other digital video modes) referred to in this paper are delivered as packet flows.

The challenge faced by engineers is to design an architecture that satisfies the requirements of every party involved in the service provision in a cost-effective way. The high-level technical requirements considered in this enterprise are: a) to support a wide range of service characteristics for existing and future applications; b) to allow the interconnection of the access network to remote Service Nodes by means of ATM; c) to allow the end-user the interconnection of its SPN(s) to the broadband access network; d) to allow interworking with other network technologies for open service interconnection. The following sections firstly give an introductory overview of xDSL technologies, and secondly, address key issues in the design of the access and transport system in order to support an integrated protocol stack in the terminal equipment.

2 Brief DSL Technology Overview

DSL technology encompasses a wide class of point-to-point digital access transmission methods (collectively termed as xDSL) over "voice-grade" single pair copper wires. The enabling technologies are highly sophisticated digital signaling processor (DSP) techniques and advanced modulation methods, such as Discrete Multitone (DMT) and Carrierless Amplitude and Phase (CAP), that extend the potential data transmission rates into the broadband range. For any of the modulation schemes the DSL design parameters can be traded-off for a given level of performance. Both CAP and DMT DSL modems use line coding to reduce the transmitted symbol rate to confine the spectrum in the lower frequency, which corresponds to lower signal loss. For shorter loops with less loss, the upper spectral range of the data transmission channel can be extended to send the symbols faster, which increases throughput.

DSL implementations can also be divided into two broad categories: baseband or passband. Baseband systems use a simple line coding technique to transport data in the 0-100 kHz band. For this reason, baseband systems cannot coexist with analog telephony on the same pair. Digital passband systems generate two or more channels well above the baseband by amplitude and phase modulation plus filtering, leaving the baseband free to support legacy voice/modem service. In spite of their relatively simple coding scheme, implementing baseband systems is complex because of the need for hybrid circuitry to couple the transmitter and receiver to a single twisted pair such that one does not interfere with the other. Furthermore, echo cancellers must be used to detect the presence of echoes due to line imperfections.

ADSL can deliver a full DS1 downstream to the subscriber over a single unloaded 24-gauge wire pair 18 kft long and higher rates over shorter line spans. Data rates up to 6 Mb/s are possible over 12,000 feet, and 8 Mb/s E2 lines can be supported over about 6,500 feet. Upstream rates presently are in the 64 to 640 kb/s range. Furthermore, ADSL was designed to coexist with conventional analog voice over the same wire pair. There are currently two competing and incompatible "standards" for ADSL. The "official" standard was initially developed within the ANSI T1E1 committee, and uses the more complex DMT technology. The marketplace "de facto" standard uses the simpler CAP technology.

Rate Adaptive DSL (RADSL) is an intelligent version of ADSL that can automatically assess the condition of the twisted wire pair and optimize the line rate to a target line quality. This is an important feature because the quality of spans varies widely depending on age, installation practices, proximity to external electrical interferers, and a variety of other factors. RADSL allows the service provider to provision service without having to measure a line and manually adjust or choose a modem to match. It also allows a provider to provision via a management system a fixed line rate to match a particular service and tariff class, rather than having to inventory a number of modems of specific data rates.

Very High Bit Rate DSL (VDSL) is an emerging technology intended to deliver multi-megabit data rates to downstream subscribers over short spans of copper wire such as the distribution of digital TV programming to the neighborhood node for FTTC applications. Currently, up to 52 Mb/s can be supported over a 1,000-foot wire pair, while upstream rates are in the 1.5 to 2.3 Mb/s range. Although several different VDSL formats have been proposed and trialed, standardization is still in the early stages.

Recently, a series of technological improvements and standardization initiatives has been launched to remove many of the practical barriers to a rapid adoption of DSL technology in the consumer arena. The common threads running through all these new DSL proposals are low speeds and splitterless implementations.

Low Speed DSL

Low speed versions of DSL limit the downstream speed to 1.5-2.0 Mb/s and upstream rates to 100-200 kb/s or so. The major change from previous implementation is a big decrease in the high frequency spectra. Either CAP or DMT modulation may be used. Lowering the line rate has several benefits to manufacturers and service providers. Most obviously, line span range is extended by operating in a lower loss region. Thus, it becomes easier for service providers to offer uniform, predictable service over their range of loop lengths. Lower top end frequencies also theoretically mean less risk of interference with other traffic on the cable. Some low speed DMT implementations could choose to separate upstream and downstream channels, eliminating the need for echo cancellation

Splitterless DSL

A splitterless DSL modem allows a direct attachment to the household wiring plant just as an analog modem. A high pass filter is incorporated on the DSL modem to reduce the DSL low frequency energy and shield the modem from voice frequency band. Transmitter power is also reduced to allow meeting the objectives for voice frequency band interference. However, the reduced power level imposes limitations on the upstream speed, since span length and bit rate is directly traded off against each other. As a result splitterless DSL systems tend to have upstream rates in the 100-200 kb/s range for spans in the 18 kft range. Because splitterless DSL modems lack a low pass filter, they must provide better equalization than before to react to line conditions. High speed splitterless ADSL is feasible and is being readied for market by several vendors.

G.Lite

G.Lite is a low-speed splitterless ADSL solution being developed in ITU-T. It is intended to support speeds of 96 kb/s to possibly 256 kb/s downstream, with 32 to 128 kb/s upstream. Data rates as high as 1.5-2.0 Mb/s of downstream bandwidth, and more modest rates upstream, are also envisioned. G.Lite also has the support of the Universal ADSL Working Group, or UAWG, a congregation of software and hardware computer vendors, network element vendors and operating companies interested in the quick development of an universal ADSL standard for high speed Internet access. Efforts like G.Lite are highly significant because they attempt to eliminate many practical installation problems, and coupled with lower speeds, remove some of the risks of introducing new services into an already complex mixture carried by the feeder network.

3 Integrated Transport and Access Network Architectures

In a rich multi-technology context, it is quite useful to have a common network architecture that allows the coexistence of new and legacy access techniques. The proposed model calls for the division of the UA device into two units, the network termination unit (NT) and the residential gateway unit (RG [5]) as shown in Figure 1. The NT provides an homogeneous access to any broadband technology by means of an ATM UNI interface (e.g. an xDSL modem with ATM interface). The residential gateway bridges from an ATM interface to any of the service interfaces (analog TV, POTS, IEEE802.3, USB, etc.). This RG unit, besides multiplexing traffic from interactive and non-interactive applications into a single data stream, performs the necessary control plane functions (not tackled here) carried transparently from/to the service node by the integrated transport-access network.

The key issue is the incorporation of an ATM interface to newly deployed User Access devices for data integrated services, while keeping the required legacy interface(s) (analog telephone, ISDN, analog TV, etc.) in the device. This means that NT modems should include an ATM interface to connect to any QoS universal multiplexer RG. At the other end of the access network, SA and TA devices provide interfaces to the service provider ATM LAN and network operator ATM transport WAN infrastructure respectively. In this way, ATM becomes the common layer for all protocols across all the platforms providing a uniform end-to-end QoS management.

3.1 ATM Transport over ADSL

As opposed to ADSL transport of STM data which provides a serial bit interface with up to 7 simplex/duplex sub-channels with synchronous multiplexing, ADSL transport of ATM data supports up to two frame-based data transport "paths" with asynchronous multiplexing [8]. The "Fast" data path is intended to provide a low data transfer delay, up to 2 msecs, as appropriate for real-time interactive applications. The "Interleaved path" is intended to provide a very low error rate and greater latency (tens of msecs).

A reference model for such an ATM-based ADSL system is depicted in Figure 2. ATR-C and ATR-U refer to the ADSL Terminal Interface for the Carrier Office end and the Remote end, respectively. The DSLAM (Digital Subscriber Line Access Multiplexer) is located at the access node.

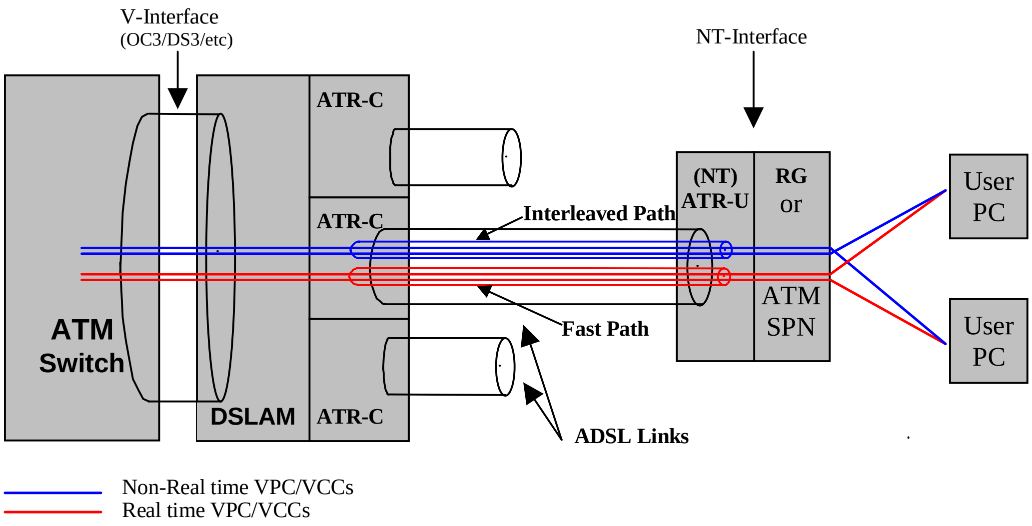

Figure 2: A Reference Model for an ATM-based ADSL System

Several other ways of implementing ATM over copper technologies are already commercially available. The Full Services Access Network (FSAN) initiative is a group of 14 PNOs working with equipment suppliers to agree upon a common broadband architecture [3] for the provision of both broadband and narrowband services. FSAN relies on a passive optical network (PON) i.e., shared downstream distribution based on fiber splitters, whose border nodes are optical network units (ONU) interfacing VDSL or ADSL. At the user side of these optional xDSL links, Network Terminations provide either ATM UNI at 25 Mb/s, ethernet or I.430/I.431 interfaces. The FSAN specification covers all the way from the UNI to the Service Node Interface (SNI) which ends in an Optical Line Terminator (OLT) interfacing VB5 to the service provider. User-server signaling should be carried transparently from the terminal equipment to the service node.

Figure 3 shows a refined view of the model depicted in Figure 1, for our concrete subject matter access technology. Notice that the access network is integrated in a high-speed ATM WAN and the service node is not necessarily directly attached to the OLT as it is in FSAN. The service nodes can reside anywhere in the ATM network. At the user access device, the network termination equipment can be either an xDSL modem (a) and (e), the ONU (b), or a full ATM-over-fiber site (c) like the service node (d). Attached to the UNI, the RG would carry out control, multiplexing and adaptation functions for the different user devices and terminal equipment. Reference [14] provides an example of a system based on this approach.

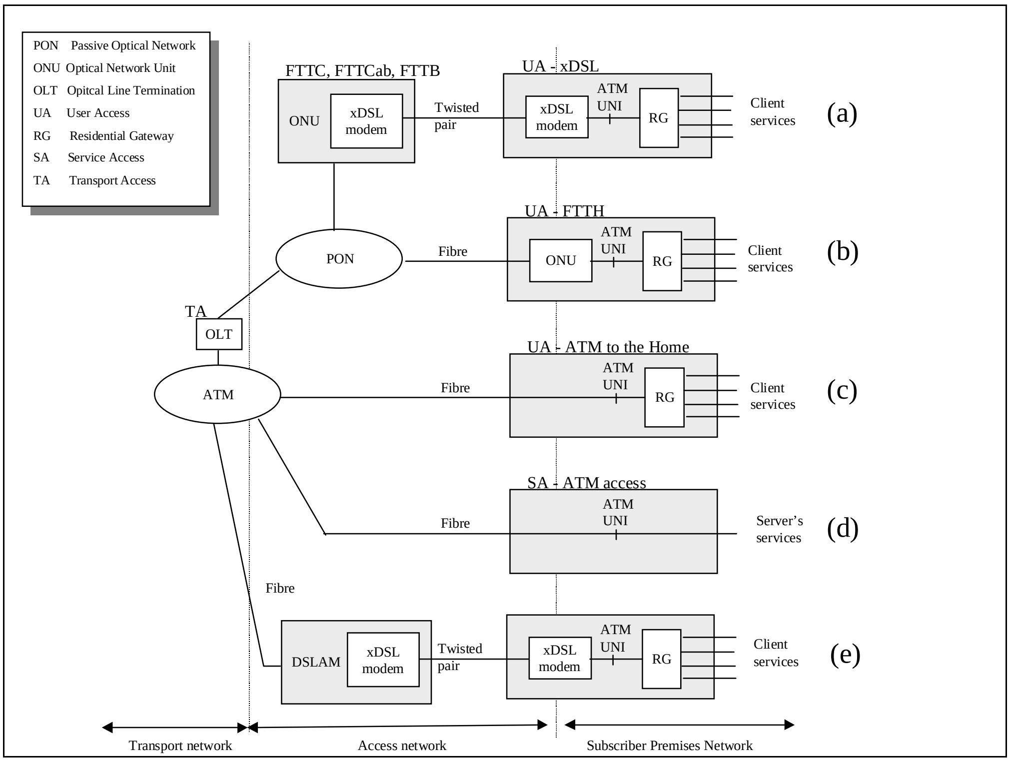

Figure 3 Integration of User Access Technologies

An important problem when trying to provide the highest xDSL rates (25-50 Mb/s) is that the required loop lengths imply a very high density of network nodes interfacing xDSL and the optical network. A number of experiments trying to extend the applicability scope of xDSL in order to avoid the massive deployment of fiber are also underway. ACTS project AC309 ITUNET [15] is evaluating a full-copper solution employing inverse multiplexing of ATM over VDSL, together with statistical multiplexing. ITUNET splits a geographical area into cells with a radio of ~1km and interconnects its nodes by a shared ATM Gigabit backbone physically built on top of the existing telephone pairs using VDSL bundling in transit before connecting to an optical network node. That is, using xDSL not only in the last mile. This could be a transitory solution in areas where the cost of the deployment of a fiber network requires a huge investment in comparison to the cost of extra modems and multiplexers involved. Again, ATM is the data transport technology chosen on top.

3.2 Why ATM to the Home/Office?

So far, several ATM-based architectures have been cited though no much rationale has been given for the introduction of ATM through the access network. Let us point out some of the technical reasons that make it convenient to use ATM as the standard interface technology.

Firstly, ATM as universal access interface would enable a seamless integration of access and backbone networks. Most digital backbone networks already deployed are based on ATM technology. Also, many head-end to central office (or multi-service center) networks use SDH, or ATM multiplexing capabilities. If ATM were used over all access media then statistical multiplexing would be possible the whole path long, and no protocol adaptation would be needed for each and every access technology.

Secondly, ATM appears to integrate a wide range of applications with different QoS requirements within a given bandwidth capacity regardless of the underlying physical media. ATM enables efficient management of bandwidth to carry heterogeneous traffic types. ATM's small and fixed packet length makes it possible to guarantee bounded delays, makes channelized statistical multiplexing feasible and enables finer implementation of scheduling policies of higher level data units.

From the network management point of view, bringing ATM to the user's network access units has other implicit advantages thanks to its connection-oriented nature: most billing, security, maintenance and operation support infrastructure that current switched service networks require can be supported [10] and makes it possible to charge on the basis of usage with an end-to-end managed QoS.

Finally, current protocol architecture trends must be taken into account too. The proposed IP switching protocol stacks, where IP routing capabilities are integrated into an ATM fabric and switching is performed at cell level by-passing router's routing tables for increased performance, is an important driving force for the deployment of IP over ATM networks. In the architecture described, routers at the Service Centers (and firewalls) performing advanced IP functions, can delegate most traffic on attached ATM switching fabric gaining throughput and setting up real end-to-end ATM circuits.

4 Architectures for xDSL-based NSP Access

The access to Network Service Providers (NSPs), where the NSPs include both Internet Service Providers (ISPs) and corporate intranets, is considered by some authors as the "killer" application for the actual deployment of broadband access networks. Figures 1 and 3 incorporate the xDSL access network model of the ADSL Forum [9]. In this model, the UA device connects to the DSLAM by means of the xDSL modems. The DSLAM provides an ATM interface that through the transport network connects to a gateway device located at the Service Node. The gateway device connects to a regional broadband network using ATM, FR, SMDS or other technology, and through this network the destination ISP or corporate network is accessed.

It is assumed that Point-to-Point Protocol (PPP) is used over ATM (over xDSL) for the UA device, and this is consistent with industry trends. Under this model, xDSL data access services are anticipated to resemble the current narrowband dial-up paradigm as significant modifications in the client PC operating system is expected to hinder the rapid deployment of xDSL technology. Data client architectures rely heavily upon the PPP protocol to provide session, authentication and IP configuration management. Common accounting, and authentication servers based on RADIUS or similar approaches should work seamlessly with sessions established using both xDSL access services as well as narrowband "dial-up" services. Tunneling protocols used to aggregate connections from narrowband Access Servers can be extended to high-speed xDSL technology.

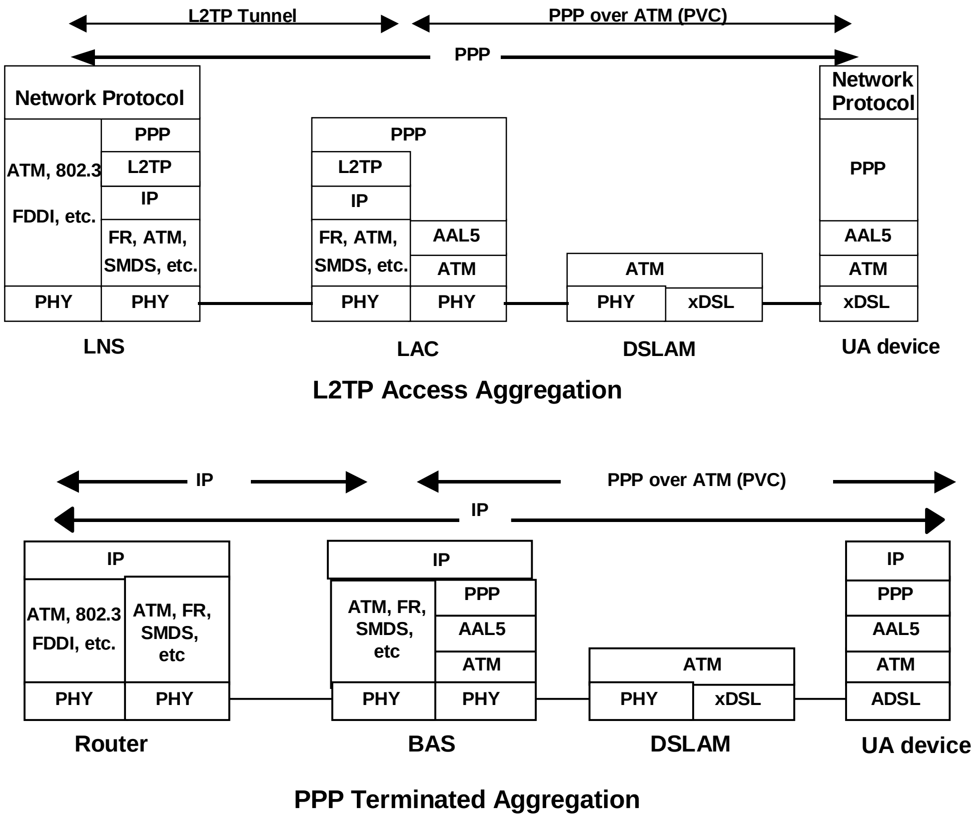

Figure 4: Comparison of L2TP Access and PPP Terminated Aggregation

Most end-to-end ATM architectures assume direct connectivity between a client and the NSP at the ATM layer. Yet, support of the ATM signaling protocols in the SPN would be unrealistic, at least initially. An approach using ATM PVCs provides an alternative solution, but no support for a notion of session within the access network. In order to support the notion of session without ATM SVCs, two architectures that enable end-customer to select an NSP through the PPP layer have been proposed: the L2TP Access Aggregation (LAA) and the PPP Terminated Aggregation (PTA). These architectures are similar in network topology and user equipment architectures (assuming IP is used as a network protocol), but differ in the way data is transported through the regional broadband network. Figure 4 provides a comparison between the protocol architectures and encapsulation methods of LAA and PTA techniques. In this figure, for simplicity, the UA and terminal protocol architectures have been integrated into one stack.

The Layer 2 Tunneling Protocol (L2TP) is a protocol for extending PPP sessions over an arbitrary network to a remote network server known as the L2TP Network Server (LNS). The user dials to a L2TP Access Concentrator (LAC) which extends the PPP session to the LNS. Figure 4 shows how the DSLAM is connected to a LAC via a pre-provisioned ATM PVC. The LAC terminates the ATM PVC, determines the users desired destination and tunnels the PPP session to that NSP. The LNS at the NSP strips off the L2TP encapsulation and terminates the user's PPP connection. This provides connectivity to the NSP in a manner similar to what dial-up modem access provides today.

The PTA technique also uses PPP over the xDSL access network. However, the PPP sessions are terminated in a Broadband Access Server (BAS) instead being tunneled all the way to the NSP as it is done in LAA. At the BAS the IP packets are extracted and forwarded over an IP-based regional broadband network to the proper NSP. Notice that, as in the LAA approach, the DSLAMs are connected to the BAS via pre-provisioned ATM PVCs. The user initiates a session by establishing a PPP connection between the user's terminal (e.g. a PC) and the BAS. The BAS provides functions such as IP address configuration and user authentication, authorization and accounting using the PPP suite of protocols. The BAS receives the user login and password and authenticates the user with the NSP through a query to the NSP's RADIUS server. An IP address and other configuration information for the user is also obtained from the NSP during this query. On the outbound side, the BAS provides an IP interface to the NSPs. After it has established a PPP session with the user, the BAS maps a user-identifier to the NSP port. This unique mapping is used to forward the user's IP packets to the destination NSP.

5 Integrated Services Support

It has been shown in section 3 an approach to design an integrated broadband architecture based on ATM transport and PON/xDSL access. This architecture uses ATM technology for the User-Network and Service Node interfaces (see figures 1 and 3). To provide a complete integrated service scenario it is also needed to design the protocol architecture that supports the different applications at the Residential Gateway and at the Service Node endpoints. Different solutions being currently proposed are shown in Figure 5, and are discussed below.

ATM-only

Because the User-Network and Service Node interfaces are based on ATM technology some authors propose that the applications be based over ATM with or without an adaptation layer. This provides QoS to the application and also shows good performance in terms of transmission overhead and delay. The disadvantages are that it requires signaling at the ATM interface (which will not be available for some time) for switched services, that it is based on end-to-end ATM service, and that it is not well suited for connectionless services. Moreover, ATM does not provide a satisfactory model for multipoint-to-multipoint applications.

In the short term, the application driver for xDSL is the provision of higher access speeds to the Internet and corporate intranets. In a packet-based network, ATM is only a link layer protocol, and so is significant only over one link, not end-to-end. These reasons lead us to believe that some applications may reside directly over ATM, but a richer protocol stack will be needed in the general case.

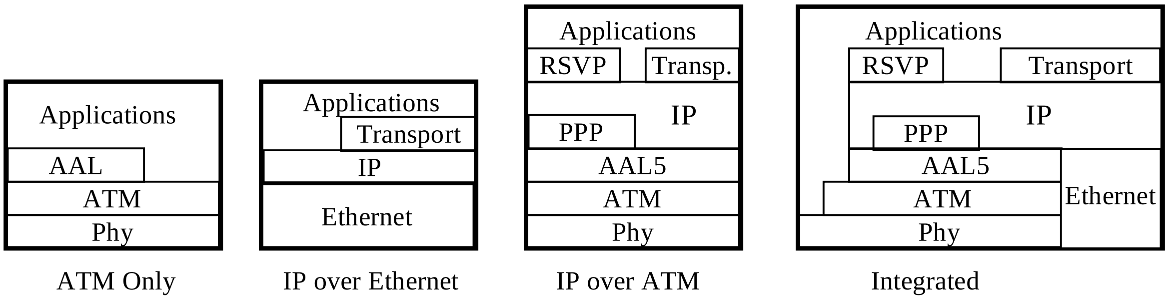

Figure 5 Protocol Architectures for the Residential Gateway

IP over ATM

Obvious advantages of using IP are that it supports connectionless services and that it provides interoperation with most networking technologies, as required for services accessible across the Service Node. IP has also been proposed to provide data services over CATV networks [10].

IP may be directly installed over ATM, or installed using an intermediate PPP layer. The former approach is appropriate for permanent IP connections over PVCs or switched ones over SVCs. The latter approach is favored by current ISPs to provide switched Internet access (as shown in the previous section) without requiring ATM signaling at the User-Network interface.

The main drawback of IP is that the current service model does not provide QoS support. However, two emerging proposals aim at solving this problem: the Integrated Internet model (IntServ [12],) which is an extension to IP conventional best effort service, and to a lesser extent the Differentiated Internet model (DiffServ [13]). The Resource Reservation Protocol (RSVP) provides the signaling plane of the IntServ model. Extensions to RSVP are also planned to support the Diffserv model.

RSVP is suited for usage of IP over serial line interfaces (or ATM CBR SVCs) and also for IP over switched network technologies capable of providing QoS. In particular, there is a mapping from RSVP to ATM's UNI 4.0. Because of this, it would be possible the short-term usage of RSVP over PVCs, and a future use over SVCs. Another advantage of the IntServ model is that multipoint-to-multipoint services are well supported because RSVP sessions are based on *destination* address, while flows are based on *source* addresses. The mapping between reserved resources and desired flows is solved in a flexible way allowing the receivers to choose between three different reservation styles: Wildcard Filter, Shared Explicit and Fixed Filter. Finally, the IntServ and DiffServ models match well with the underlying ATM service modes. This is shown in Table 1 that provides a mapping from IntServ and DiffServ capabilities into ATM service categories.

ATM Service Categories (ATM Forum)	**Integrated Services**		**Differentiated Services**		**Best effort**
	Guaranteed Service	**Controlled Load**	**Expedited Forwarded**	**Assured Forwarding**	
CBR	√		√		
RT-VBR	√		√		
NRT-VBR		√		√	
ABR		√		√	√
GFR		√		√	
UBR					√

Table 1: Service mapping from ATM into the IntServ and DiffServ models

The *IP over ATM* architecture described is already being developed and field trialed in different environments (e.g. ACTS BTI project [14].)

Integrated Architecture

The advantages of the different architectures, plus the provision of an Ethernet interface for data SPN, may be integrated into the IP over ATM architecture. The only requirement to integrate the ATM-only architecture is allowing the applications to access directly the ATM service. This may be very convenient in some cases as for video distribution applications that require low delay and delay jitter, and low transmission overheads. Let us remark that applications wishing to use directly the ATM service need end-to-end ATM service.

The provision of an Ethernet interface may be accomplished by an IP routing function in the Residential Gateway. Actually, the routing approach allows to provide any networking interface supported by IP, with the obvious restriction that the internetworking protocol must be IP.

Then main drawback of the integrated architecture is the complexity and cost of the NT and RG devices.

Ethernet

Finally, a quite different approach would be that the NT device offered an ethernet interface to the user instead of ATM. Ethernet and fast-ethernet are a more convenient and affordable technology for SPNs than ATM LANs. Furthermore, user equipment would be compatible with CATV networks that in most cases provide ethernet at the user-network interface. However, the advantages of providing an Ethernet interface at the NT have to be balanced against the corresponding difficulties to provide QoS to applications, and the fact that Ethernet does not support well the concept of “session” for switched services.

6 Conclusions

A rich set of broadband access copper technologies is available in the market today, and more are coming out of the laboratories, rapidly moving to standardization. The most likely future scenario will be one where many different technologies will coexist. This may cause interconnection problems between different technologies in the access network, and between end-system equipment and the interfaces deployed in the user and Service Node end-points. For reasons of economy of scale and service management, it is important to harmonize the different access methods, as well as the interfaces and protocol architectures for integrated services.

The access network architecture here described, in the line of existing specifications and experiments, harmonizes the interconnection between PON, xDSL and native ATM technologies. One relevant feature is the usage of ATM as the technological solution for integrated services at both the Service Node and the end-user interfaces. The advantages of ATM are its traffic multiplexing capabilities, good support for multicast, end-to-end QoS management and versatility. ATM is one of the preferred solutions of the FSAN group, and some prototype implementations are already available. Setting the ATM interface at the user premises makes it possible the seamless migration to newer access technologies while preserving user devices, and also allows a smoother migration to new services. The high level model presented in the introduction could apply also to CATV access networks, but the shared media nature of CATV at the user-network interface makes it difficult to extend the proposals presented here to that technology.

Another relevant aspect is the standardization of the protocol architecture of the equipment located at the end-user (Residential Gateway) and Service Node (routers, video servers, ...) end points. IP is a clear candidate for a service integration technology. Its main drawback is its lack of QoS support, but the incorporation of the IntServ architecture provides satisfactory solutions to most requirements. The usage of IP is obviously very suitable for ISPs. It is important to take into account the requirements from ISPs because they represent an important driver for the deployment of broadband accesses. Although ISPs currently back two different protocol architectures, both of them are similar at the user side. For this reasons, the usage of IntServ and IP plus optionally PPP are incorporated in the protocol architecture described. Finally, to take into account the requirements of high bandwidth applications such as video servers, a direct access from the applications to ATM services is considered as convenient.

References

[1] L. A. Ims, D. Myhre and B. T. Olsen, “Economics of Residential Broadband Access Network Technologies and Strategies,” *IEEE Network*, January/February 1997, pp. 51-57.

[2] R. E. Hundt and G. L. Rosston, “Alternative Paths to Broadband Deployment,” *IEEE Communications Magazine*, July 1998, pp. 93-95.

[3] J.A. Quayle (Ed.), “Full Services Access Network Requirements Specification,” issue 3, http://www.labs.bt.com/profsoc/access/, August 1998.

[4] J. Forster, *et. al.*, “An Integrated Architecture for Video, Voice and IP services over SONET and HFC Cable Systems,” *Cisco Systems White* Paper, October 1997.

[5] C. A. Eldering, “Customer Premises Equipment for Residential Broadband Networks,” *IEEE Communications Magazine*, June 1997, pp. 114-121.

[6] K. Asatani and Y. Maeda, "Access Network Architectural Issues for Future Telecommunication Networks," *IEEE Communications Magazine*, August 1998, pp. 110-114.

[7] T. C. Kwok, "Residential Broadband Internet Services and Application Requirements," *IEEE Communications Magazine*, June 1997, pp. 76-83.

[8] J. Bingham and F. van der Putten (Eds.), "Interface Between Network and Customer Installation, Asymmetric Digital Subscriber Line (ADSL) Metallic Interface," ANSI T1 Draft, Sept 26 1997.

[9] Core Network Architectures for ADSL Access Systems V1.01. ADSL Forum. March 1998.

[10] B. Khasnabish, "Broadband to the Home (BTTH): Architectures, Access Methods, and the Appetite for It," *IEEE Network*, January/February 1997, pp. 58-69.

[11] E. J. Hernandez-Valencia, "Architectures for Broadband Residential IP Services over CATV Networks," *IEEE Network*, January/February 1997, pp. 36-43.

[12] R. Braden, D. Clark and S. Shenker, "Integrated Services in the Internet Architecture: An Overview," RFC 1633, June 1994.

[13] S. Blake, D. Black, M. Carlson, E. Davies, Z. Wang and W. Weiss, "An Architecture for Differentiated Services," IETF Diffserv WG Draft, April 1998.

[14] A. Azcorra *et. al.*, "Broadband Trial Integration," proceedings of IDC' 98 Distributed Conference, September 1998.

[15] E. Edvardsen, "Integration of DSL technologies and ATM to deliver broadband services to the user", proceedings of Interworking'98, Ottawa, July 1998

Biographies

ARTURO AZCORRA [M] (azcorra@it.uc3m.es) received a M.Sc. degree in Telecommunications from Technical University of Madrid in 1986 and Ph.D. degree from the same university in 1989. He became in 1990 an associate professor at the Department of Telematics Engineering, Technical University of Madrid, Spain. Since 1998 he is a professor at U. Carlos III of Madrid, Spain. Current research projects include broadband networks, multicast teleservices, intelligent agents, and IP/ATM convergence.

ENRIQUE J HERNANDEZ-VALENCIA [M] (enrique@bell-labs.com) received his B.Sc. degree in Electrical Engineering from the Universidad Simón Bolívar, Venezuela in 1982. He received his M.Sc. and Ph.D. degrees in Electrical Engineering from the California Institute of Technology, Pasadena, USA, in 1985 and 1987, respectively. Since joining Bell Laboratories in 1987 he has been actively involved in the research, design and development of high-speed data communications networks. Research areas of interest include networking protocols, broadband traffic management and congestion control and transport/switching architectures, among others.

JULIO BERROCAL [M] is a professor of computer networks at Technical University of Madrid, Spain (DIT-UPM). He received a Telecommunication Engineer degree in 1983 and a Doctor in Telecommunication degree in 1986, both from UPM. He has been involved in the design and analysis of many computer systems and networks, including local and wide area networks, working in collaboration with public and private organizations. His current research interests are in management of telecommunication networks and services, multimedia networking, broadband networks and interconnection of heterogeneous networks.

DAVID LARRABEITI [M] is interim associate professor in the department of Communication Technologies at the University Carlos III of Madrid. He received his M.Sc. and Ph.D. degrees in telecommunication engineering from the Technical University of Madrid in 1991 and 1996 respectively. He has been involved in the design of large multipoint networks using IP over ATM to support worldwide distributed conferences. His research interests include quality of service networking and multimedia applications, real-time systems and validation of computer protocols.