INTEGRATED SERVICES TO THE HOME/OFFICE OVER XDSL

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ABSTRACT

This paper deals with different technical approaches aiming at achieving full service integration at the customer premises. The work is structured as follows. Firstly, a target network model is described at a high level of abstraction, where service nodes and subscriber premises networks are connected by an ideally integrated access and transport network. As usually the transport network is based on ATM, this work dicusses the suitability of extending ATM to the access network and current approaches on carrying ATM over ADSL. Finally, in order to take advantage from the QoS awareness of this integrated network and bring end-to-end QoS to the user, there is a need to discuss about the most suitable network architecture compatible with existing technologies that fits better with present and next future requirements. The paper depicts several architectural approaches that try to cover most of these goals.

1 AN OVERALL VIEW OF THE TARGET NETWORK MODEL

A number of studies [1,2] show that, up to the date, no specific access technology seems to be dominant under a techno-economic criterion. This means that the access infrastructure actually deployed in the near future will consist of a mix of technologies. Digital Subscriber Line (xDSL), Hybrid fiber coaxial systems (HFC), several forms of passive optical networks (PON), fixed wireless local loop (WLL), multipoint distribution systems (xMDS), different earth orbits satellite communication systems (xEO), and more technologies next to come will coexist, will compete and should ideally be transparent to the end user. Economical factors will of course drive most decisions in the actual deployment of access infrastructure. However it's also engineers' task to define the most flexible framework towards which implementations should be oriented, and then make numbers to tell whether an extra investment today will be crucial in the future QoS market battleground.

Let us focus on xDSL and let the reader generalize to other access network technologies. An ideal target network model that enables the provision of broadband residential services over xDSL is shown in Figure 1 [4,6]. This network model, presented in [16], is the same, at this level of abstraction, as the one used for HFC access networks.

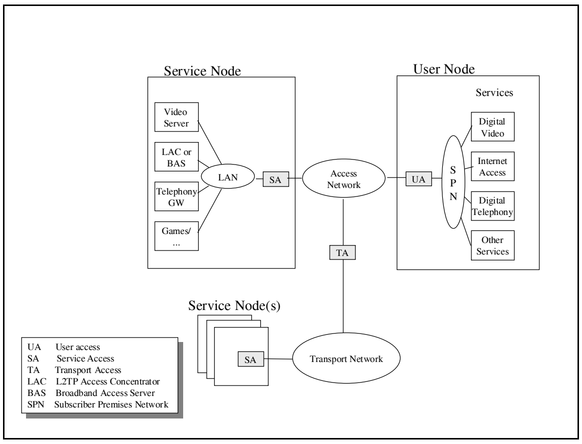

Figure 1. Target network model.

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.

2 ATM-BASED INTEGRATED ACCESS - TRANSPORT NETWORKS

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. Figure 2 shows a generic ATM-based network architecture that provides an homogeneous access to broadband service supporting QoS from a user to a network service(s) provider(s) across any access network and an ATM transport backbone.

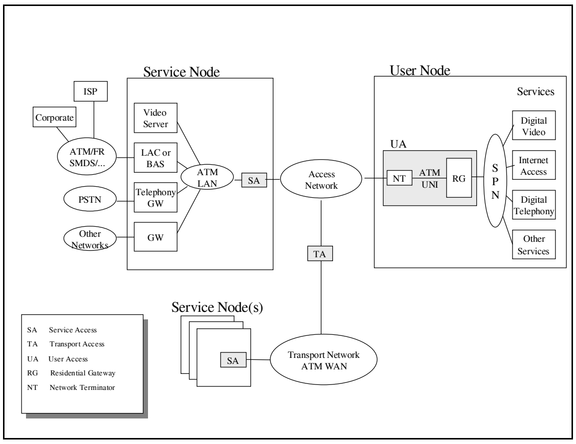

Figure 2. ATM-based integration of access and transport networks.

Three functionally different access devices have been defined: User Access (UA), Service Access (SA) and Transport Access (TA). The UA [5] at the user node provides shared network access to all the digital interactive services offered. The UA concept is split into two units, the network termination unit (NT) and the residential gateway unit (RG). The network termination provides an homogeneous access to any broadband technology by means of an ATM UNI interface e.g., xDSL modem with ATM interface, now commercially available. 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.

About the convenience of ATM to the Home/Office

The previous design decision has important consequences. The introduction of ATM in the access network needs a careful analysis. Letting alone economic factors , as already stated, (obviously not because of its little importance -quite the contrary!- but for the sake of the purely technical viewpoint here adopted) let us point out some of the technical reasons that, from the authors' view make it convenient to use ATM as the standard interface technology.

- 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.
- ATM claims to achieve the effective integration of a wide range of applications with different QoS requirements within a given bandwidth capacity regardless of the underlying physical media. ATM - used as a multi-QoS supporting network protocol rather than a mere transmission medium as done most of the times- 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 levels 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 and of an end-to-end managed QoS.
- The proposed *IP switching* technics, 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 switches gaining throughput and setting up real end-to-end ATM circuits.
- Support of *multicast* by ATM makes it an efficient transport medium for high speed multipoint applications. Nevertheless, its limits concerning multicasting in hetereogenous QoS environments (each user wants to receive the same flow with different QoSs) shouldn't be forgotten.
- Finally, in the long run, choosing a versatile interface such ATM would enable a *smoother migration to new access technologies*. The system would be upgraded by simply exchanging the physical-medium-dependent interface card NT in the UA unit with a new one (both in the user and operator sides) without the need for a complete redesign of the multimedia transport architecture. Since new applications are designed QoS-aware, upgrading the underlying network capacity does not imply major changes in applications as long as the user-network interface is preserved. This factor may justify the higher investment implied beyond the raw technical viewpoint here described.

3 ATM 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). An ADSL system may operate in a Single Latency mode, in which all data are allocated to one path (Fast or Interleaved), or a Dual Latency mode, in which data are allocated to both paths. The allocation of channel capacity between the "Fast and Interleaved data paths is programmable on an ADSL link basis. Also, further multiplexing of different payloads is envisioned to be embedded within the ATM data stream by means of different Virtual Path and/or Virtual Circuit Channels (VPC/VCCs).
A reference model for such an ATM-based ADSL system is depicted in Figure 3. ATR-C and ATR-U refer to the ADSL Terminal Interface for the Carrier Office end and the Remote end, respectively. The DSLAM is the ADSL Access Multiplexer at the access node. Data bytes at the V/T interfaces are transmitted in accordance with ITU-T recommendations I–361 and I-432.

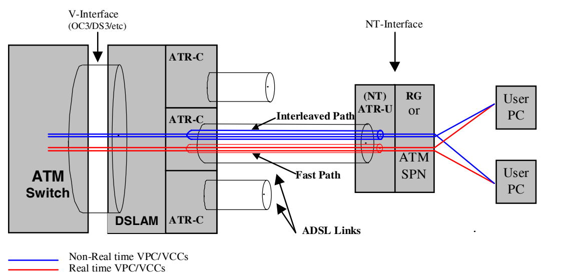

Figure 3. A reference model for an ATM-based ADSL system

As well known, ATM provides its own style of data transfer modes/service categories. Table 1 provides a plausible mapping of the ATM service categories into ADSL data transport paths. It should be noted that the Fast path is essentially a constant rate channel, thus, traffic shaping may be required at the ingress points to the ADSL system.

ADSL Data Paths	ATM Service Categories (ATM Forum)					
	CBR	RT-VBR	NRT-VBR	ABR	GFR	UBR
Fast	√	√				
Interleaved			√	√	√	√

Table 1. Plausible mapping of ATM Service Categories to ADSL transfer paths.

Coordinated efforts

Some other ways of implementing ATM over copper technologies are already commercially available, fueled by the interest telecom operators have set on this protocol as a manageable common interface to the user. The Full Services Access Network (FSAN) initiative is a group of 14 PNOs working with equipment suppliers to agree upon a common broadband access system for the provision of both broadband and narrowband services. This architecture is defined in a public requirements specification [3]. 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 4 shows a refined view of the model depicted in Figure 2, for xDSL access technology.

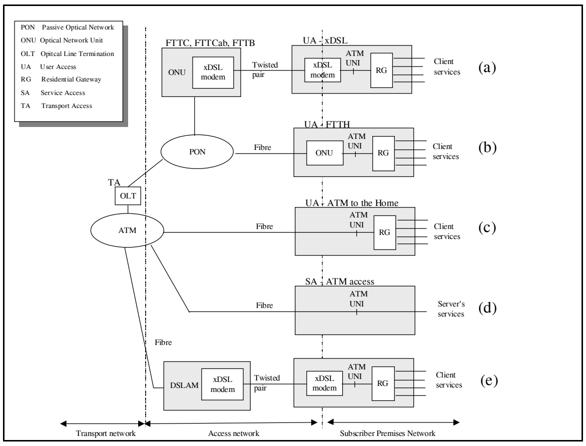

Figure 4. Integration of User Access Technologies.

In a similar way to FSAN, the architecture depicted in Figure 4 is based on ATM over a PON+xDSL access network. Unlike FSAN specification and in a more general fashion, the access network is integrated in a high-speed ATM WAN and the service node is not necessarily directly attached to the OLT. The service provider can reside anywhere in the global ATM network. At the user access device, the network termination equipment can be either an xDSL modem (a) and (e), or the ONU (b), or be 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] is an example of system based on this approach.

Inverse multiplexers

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.

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 2 and 4 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.

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 as the notion of session within the access network is provided with the addition of ATM SVCs. 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 5 provides a comparison between the protocol architectures and encapsulation methods of L2TP access and PPP terminated aggregation techniques. In this figure, for simplicity, the UA and terminal protocol architecture have been integrated in one stack.

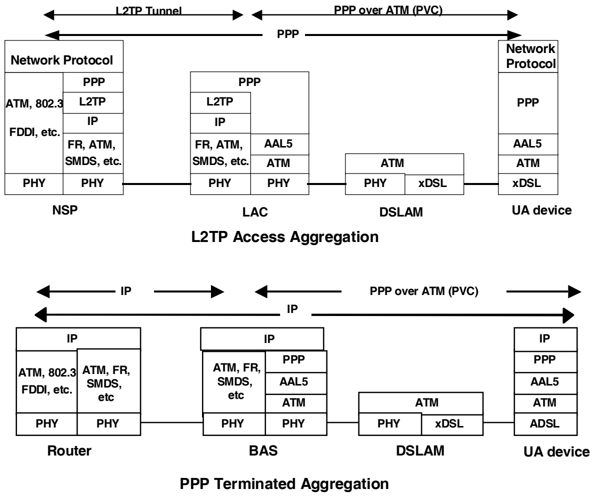

Figure 5. Comparison of L2TP Access and PPP Terminated Aggregation.

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). L2TP was originally designed to support mobile scenarios where the user does not dial directly into his destination ISP or Corporate dial server. Instead, the user dials to a L2TP Access Concentrator (LAC) which extends the PPP session to the LNS. Figure 5 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 LAC interfaces to the regional broadband network with the requested network technology by the NSP (e.g., ATM). The NSP/LNS 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.

PPP Terminated Aggregation (PTA) also uses the suite of PPP protocols in the xDSL access network. However, instead of PPP being tunneled all the way to the NSP, the PPP sessions are terminated in a Broadband Access Server (BAS). IP packets are extracted and forwarded over an IP-based regional broadband network to the proper NSP. Any network technology (e.g. Frame Relay, ATM, SMDS, private lines, etc.) that can encapsulate IP packets can be used between the NSP and the xDSL access network.

The NSP need not understand or support PPP functions.
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 terminates PPP and forwards the user's IP traffic to the appropriate NSP to which the user is associated on a session-by-session basis. 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

Creating a fully integrated service scenario implies the careful design of a 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 6, 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 directly 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. Microsoft (under Winsock2) and some application vendors support this approach. 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. One can shift from one link layer protocol to another at any point necessary to interface with a different network, ATM to frame relay for example. 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.

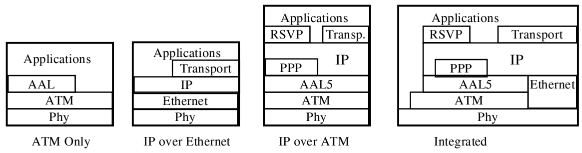

Figure 6. Some alternative protocol stacks.

Ethernet

Another common approach is offering an ethernet interface to the user instead of ATM. Ethernet (and fast-ethernet) has become a well-accepted and affordable technology even for SPNs at home. Furthermore, user equipment would be compatible with CATV networks that in most cases provide ethernet at the user-network interface. However, the usage of ethernet makes it difficult to provide QoS to applications, and does not support well the concept of "session" for switched services. An ethernet interface may be provided as one of the specific interfaces (besides analog TV, POTS, etc) available at the Residential Gateway, but we do not consider it a viable alternative for Integrated Services support.

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 integrated 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. As both solutions may easily coexist, an integrated architecture could incorporate the two of them.
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.

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 2: Service mapping from ATM into the IntServ and DiffServ models.

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 2 that provides a mapping from IntServ and DiffServ capabilities into ATM service categories.

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 ATM-only and Ethernet architectures may be integrated into the IP over ATM architecture without a significant increase in complexity.

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. This is not a restriction for user-to-user applications as long as both users are connected to the proposed access or transport network. However, for server-based applications (such as video distribution/retrieval) the servers must be located at Service Nodes, unless a specific application layer gateway exists to provide transit across the Service Node.

Finally, 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. This solution does not show the network-protocol independence of the Ethernet architecture, but if a network protocol different to IP is required by the user, it is very likely that a tunneling or encapsulation method is already defined to transport it over IP.

5 CONCLUSIONS

Many broadband access copper technologies are 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.

In order to take advantage from the QoS awareness of this integrated network and bring end-to-end QoS to the user, the most suitable network architecture compatible with existing technologies that better meets present and next future requirements must be found. This paper describes several architectural approaches that try to cover most of these goals. The standardization of the protocol architecture of the equipment located at the end-user (Residential Gateway) and Service Node (routers, video servers, ...) end points is hence a key issue. IP is one 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.

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