Technical Report
TR-004

Network Migration

December 1997

ABSTRACT:

This project describes network migration options for telco access networks incorporating ADSL. Different telcos will have different legacy systems, regulatory and competitive environments, broadband strategies and deployment timescales. Hence it is not feasible to make all encompassing recommendations for network migration options. This project seeks to capture the drivers that may lead a telco to consider a particular migration path. It then presents the various technical options together with the salient features, advantages and disadvantages to assist telcos in forming evolution plans for an access network that will incorporate ADSL. It is hoped that this working text will serve as a useful reference text for both the technical and marketing professionals in the ADSL Forum.

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1. STATEMENT OF PROJECT

The objective of this project is to capture ADSL network migration options for a set of defined initial and target network scenarios, identifying the key issues associated with each option. It will also describe related technical issues that may impact the deployment of an ADSL access network.

The scope of the project is any access network migration scenarios that would involve use of ADSL or VDSL on a customers line in either the initial or target network scenarios. i.e. evolution to or from ADSL / VDSL.

The primary focus is ADSL and VDSL technologies and architectures. However, to complete the picture of evolution scenarios, other xDSL technologies are not specifically excluded.

The approach taken is that for each evolution situation, define it by :-

- Starting network scenario
- Target network scenario
- Drivers (factors that will initiate and influence the migration)
- Options (including advantages and disadvantages)

Each evolution situation forms an individual sub-section within this Network Migration Working Text. In addition generic factors influencing migration to ADSL are also described.

2. FACTORS INFLUENCING MIGRATION TO ADSL

This section seeks to list some of the major factors influencing the willingness, ability and speed of a telco or other service provider to migrate their access network to one that embraces the deployment and use of ADSL technology[1]. The influencing factors are categorised as being related to either network/architecture issues, equipment issues or business/service issues. Some of these may be regarded as critical success factors for ADSL.

2.1 NETWORK/ARCHITECTURE RELATED FACTORS

(a) The presence of loading coils in some telco networks. This may have to be dealt with in the same way as they are for ISDN.

(b) The degree to which Digital Loop Carrier (DLC) technology has been deployed to provision narrowband services, especially the older SLC96 and SLC5 systems. How is ADSL to be jumpered onto the final distribution copper? How will POTS from the SLC be ÒmergedÓ with the ADSL signal via the splitter? Is the ADSL housed in an adjacent remote housing?

(c) How will ADSL be housed and provided in next Generation DLCs (NGDLC)?

(d) The remainder of the broadband network needs to be installed to exploit ADSL. E.g. ATM switches and backbone network or other broadband data overlay network, VoD servers etc.

(e) There is no Òplug and playÓ standard network solution available in a turn-key form yet. It requires extensive network design, integration and performance analysis skills.

[1] Factors influencing migration FROM ADSL are described in sub-sections 6.8 & 6.9

(f) Solutions to the problem of dynamic IP address assignment and binding to physical network hardware addresses, particularly over ATM networks need to be solved, standardised (with one approach, not many) and widely supported.

(g) Security concerns, especially with some of the earlier proposed router/Ethernet architectures need to be mitigated and the solutions disseminated.

(h) The integration of ADSL into the existing copper access network. Changes required to operational processes, test equipment and line-test procedures, network management systems[2] and their databases. In addition, field personnel need to be trained to understand, install, operate and maintain this technology. Data equipment such as ATM or Ethernet/router interfaces will be new to many of them.

(i) Quantifying the impact on existing services (POTS band equipment on the same pair and spectral compatibility with other services on adjacent pairs) and removing any concerns.

(j) Concern on how to navigate through all the existing transmission technology ÒbarriersÓ to ADSL that are in todayÕs network e.g. ISDN, pair-gain systems, fibre systems. Also, concern about what barrier ADSL may be to future technologies such as FTTN or FTTK with VDSL, particularly if the telco has made a public commitment to VDSL or entered into a longer term contract. Will they have to fork-lift any ADSL deployed today to make way for the VDSL deployment committed to for tomorrow?

(k) Satisfactory solutions to the home-wiring topology and installation and process. Can the customer self-install the ADSL remote unit? If so under what circumstances? What POTS splitter locations are convenient, work well, facilitate fault demarcation and look OK from the customerÕs perspective? Is an active or passive NT approach best?

(l) Satisfactory solutions (equipment and process) to identifying the bit-rate that can be supplied (if at all) to an individual customer. What is the process from the point of sale (e.g. Can I have 2 Mbit/s VoD service?) to service provisioning with a high degree of confidence and minimal failures.

(m) The ability of DSL products to ÒfitÓ existing ISP network architectures in terms of existing router interfaces, impact on firewall, multi-cast, authentication capabilities, tools/methodology for Radius database updates etc.)

2.2 EQUIPMENT RELATED FACTORS

(a) Cost of equipment. When will it reach its floor and what will this be? Questions over port density (number of customers per line card, related to power consumption) and rack density/over booking levels. The common equipment costs at start-up represent exposed capital expenditure until there is a high service take up and hence equipment utilisation.

(b) Spectral compatibility of ADSL equipment with other DSL technologies, especially in the unbundled Òdark copperÓ regulatory regimes affecting some networks.

(c) Physical space, power and cooling requirements in the CO. Linked to rack density issues in (a). A particular concern for ISPs/CLECs seeking co-location in ILEC Cos. These factors will also be very important to externally sited ADSL electronics for example when embedded in a next generation DLC.

(d) Physical size and design aesthetics of the remote ADSL customer unit including the POTS splitter.

(e) The best choice of physical interface on the remote ADSL customer unit e.g. Ethernet, ATM25, two ATM25, one ATM25 plus one Ethernet, Universal Serial Bus (USB), RS422 etc.

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[2] The contribution “Management of ADSL-Based Access Network” ADSLForum97-109 by Tsu-Kai Lu et al describes the evolution issues associated with ADSL network management.

(f) The capability and current status of operational support systems for ADSL (element managers etc.)

(g) The availability, cost effectiveness and ease of use of appropriate test equipment for commissioning ADSL installations (e.g. line qualification testing, field deployable ATM testers for DSLAM commissioning etc.)

(h) The status of equipment standards (approved and de-facto) for ADSL (line code, ATM via dual latency), ATM signalling and IP over ATM (inc. LANE, MPOA etc.) and subsequent impact on interoperability. Availability of equipment implementing these standards such as software application driven SVC set-up.

(i) Lack of turn-key end to end network equipment from ATM switch to CPE with inherent protocol stacks and plug & play software applications.

2.3 BUSINESS/SERVICE RELATED FACTORS

(a) Need for a well defined strategy and service proposition backed by a viable business case with acceptable levels of risk (to both technology and market).

(b) Forced to deploy ADSL in response to competition (by for example cable modems) when the telco business proposition isnÕt fully ready yet.

(c) Lack of confidence in the broadband market and concern over maturity of broadband technology inhibits some telcos from committing to large volume procurements in the near term. This holds equipment prices high which doesnÕt help the telco business case unless a supplier is prepared to drop margins and carry all the risk with a loss-leader.

(d) The process for identifying customers in range of constant bit-rate (CBR) services such as VoD to be delivered over ADSL isnÕt accurate or cost-effective enough. This impacts on the marketing method for such services and the process for deciding on when/where the point of sale occurs.

(e) The impact of regulations on service packaging, unbundling, cross-subsidisation and accounting separation limit the degrees of freedom of some telcos e.g. are they allowed to deliver broadcast services over ADSL as has been trialled in France and Australia? Do they have to ensure spectral compatibility with other service providers exploiting dark-copper or does the incumbent telco have full control over all ADSL installed on their network?

(f) Concern over the impact of ADSL on existing product lines such as ISDN and T1 or E1 private circuits. When is the broadband ADSL market mature enough to risk eating into these revenue streams?

3. ACTIVE AND PASSIVE NT ISSUES

The regulatory view of who owns the remote ADSL unit together with the exact physical manifestation of the end-point of the telco network can affect the preferred ADSL remote unit form-factor. This in turn can have a profound impact on migration to and beyond ADSL-based networks. In some telco networks (such as in the USA) the regulatory regime dictates that the remote ADSL unit at the customer end of the line is Customer Premises Equipment (CPE) owned by the customer. Hence the network termination (NT) presented to the customer is a Òwires-onlyÓ interface and is sometimes termed ÒpassiveÓ In other networks such as in many European countries, the ADSL remote unit is itself considered part of the access network. Hence the NT interface presented to the customer is the ADSL customer interface connection (e.g. 10baseT Ethernet, ATM 25 etc.). In this latter scenario, the NT contains the ADSL electronics and is hence termed ÒactiveÓ Hybrid architectures where the POTS splitter is separated from the ADSL remote unit are possible and some of these splitters may themselves be active requiring back-powering from the ADSL remote unit. However, the basic definitions of active/passive NT and the relative merits are broadly the same.

ADSL vendors have responded to the different markets and regulatory environments for the ADSL remote unit by developing two basic types of ADSL remote unit. The first was a stand alone ADSL box (typically wall mounted) appropriate for both types of regulatory environment (i.e. wires only and active NT). In a wires only passive NT regime, this would constitute CPE (owned or leased by the customer), in an active NT regime it would represent the end of the network (owned by the telco). The second type of ADSL remote unit takes the form of a plug-in PC card (sometimes called an ADSL NIC - Network Interface Card). This has a lot of synergy with CPE (e.g. the PC it resides in) and so is more aimed at the passive NT environments. In future it may spawn further variants such as ADSL transceivers integrated into set-top boxes or digital TVs.

This section presents a list of the advantages often cited for each approach. To keep it simple it compares a stand alone active NT ADSL remote unit with a passive NT where the ADSL is embedded in CPE such as on a PC card.

3.1 ADVANTAGES OF A STAND-ALONE ACTIVE NT ADSL REMOTE UNIT

(a) Facilitates evolution of the access network without impact on the customers CPE or home wiring. ADSL, VDSL, FTTH and wireless delivery systems could all have the same customer interface (e.g. ATM25) so that the access network can be provisioned and evolved or upgraded with minimal impact on the customer or their investment in CPE.

(b) The independence of the customer interface from the access delivery mechanism makes it easier for customers to move between different operators and service providers whilst protecting their investment in CPE and home wiring.

(c) Allows interactive multi-media services in the home to gracefully evolve to multiple CPE connections via a separate home bus having started from a single PC or set-top box. No MAC protocol is needed within the ADSL equipment as for a multi-user passive bus approach.

(d) The access network equipment and CPE are not inextricably locked into each other enabling each to evolve independently at the fastest rate the market drives them to. It removes dependencies such as the latest flavour of PC bus to build ADSL cards for. Also, keeping the network and CPE distinctly separate helps to manage some of the problems of limited line card/remote unit interoperability in the early years. ISDN took several years to get interoperability without performance loss. ADSL is more complex.

(e) Allows asymmetric access (e.g. via ADSL or asymmetric VDSL) with a symmetric home bus.

(f) Simplifies ADSL (and VDSL) provisioning and service penetration. No additional margins or loop length needs to be factored into deployment rules to account for losses in the home wiring.

(g) Easier to guarantee a quality of service (QoS) since the DSL system doesnÕt have to operate over uncontrolled customer wiring.

(h) Facilitates fault demarcation by using loopbacks etc. to determine if a fault is with the access network and ADSL or in the CPE and home wiring (which may be the customers responsibility). This enables the telco to outsource technical support and trouble shooting more easily. It doesnÕt require PC experts to understand ADSL or vice-versa. This could reduce the whole-life cost of ownership of ADSL for the telco.

(i) Reduces the risk to the telco of the ADSL system damaging the customers PC. Copper lines can be struck by lightning, also, PC hardware faults may damage a PC-based ADSL card. The mutual telco-customer liability is reduced with a stand alone ADSL customer unit. This may be particularly important to the telco if they lease the ADSL remote unit to the customer.

3.2 ADVANTAGES OF A PASSIVE NT WITH ADSL REMOTE UNIT EMBEDDED IN CPE

(a) Less ÒboxesÓ on the customer premises therefore more aesthetically pleasing.

(b) Lower capital cost per customer due to less boxes. More functionality put on the PC card so connector, PCB costs etc. shared across more functionality. Hence lower market entry costs.

(c) Simpler powering arrangements (e.g. from the PC).

4. CLASSIFICATION OF MIGRATION OPTIONS

The Network Migration Project team has produced the following list of evolution scenarios for study. These scenarios have been classified as low, medium or high priority and whether they are relevant to the shorter or longer term decisions of telcos. The initial focus of work has been on those scenarios considered high or medium priority as indicated in the final column.

Starting Network Scenarios	Target Network Scenarios	Timeframe of Scenario	Priority	Details in Section
1. Internet access via voiceband modem	Internet access via ADSL	Now	High	6.1
2. 2nd line POTS via DAML	ADSL delivered service	Now	Medium	6.2
3. ADSL from CO	ADSL from DLC	Future	High	6.3
4. ISDN for internet access	ADSL for internet access	Now	High	6.4
5. Internet only via ATM ADSL (DSLAM with10BaseT presented to customer)	ÒFull serviceÓ set via ATM ADSL (DSLAM with ATM presented to customer)	Future	High	6.5
6. Internet only via ÒIPÓ ADSL (Router plus Ethernet switch)	ÒFull serviceÓ set via ATM ADSL (DSLAM with ATM approach))	Future	High	6.6
7. Internet only via ÒIPÓ ADSL (Router plus Ethernet switch)	ÒFull serviceÓ via ÒIP-onlyÓ ADSL (10BaseT presented to customer)	Future	High	6.7
8. ADSL service delivery	VDSL service delivery	Future	High	6.8
9. Next generation DLC with ADSL (RAM)	ONU with VDSL or ADSL (FTTK)	Future	Medium	6.9
10. VDSL for residential services	VDSL for business services	Future	Low	6.10
11. ADSL for business services	ADSL for residential services	Future	Low	6.11
12. ADSL & POTS	ADSL & 2nd line (2xPOTS)	Future	Low	6.12
13. FTTNode & long range VDSL	FTTK & short range VDSL	Future	Low	6.13
14. FTTNode & VDSL	FTTH	Future	Low	6.14
15. HDSL for Internet access	ADSL for Internet access	Now	Medium	6.15
16. IDSL for Internet Access	ADSL for Internet access	Now	Medium	6.16

Table 1 : Classification and Prioritisation of Identified Migration Paths

5. OVERVIEW OF MIGRATION OPTIONS RELATIONSHIP

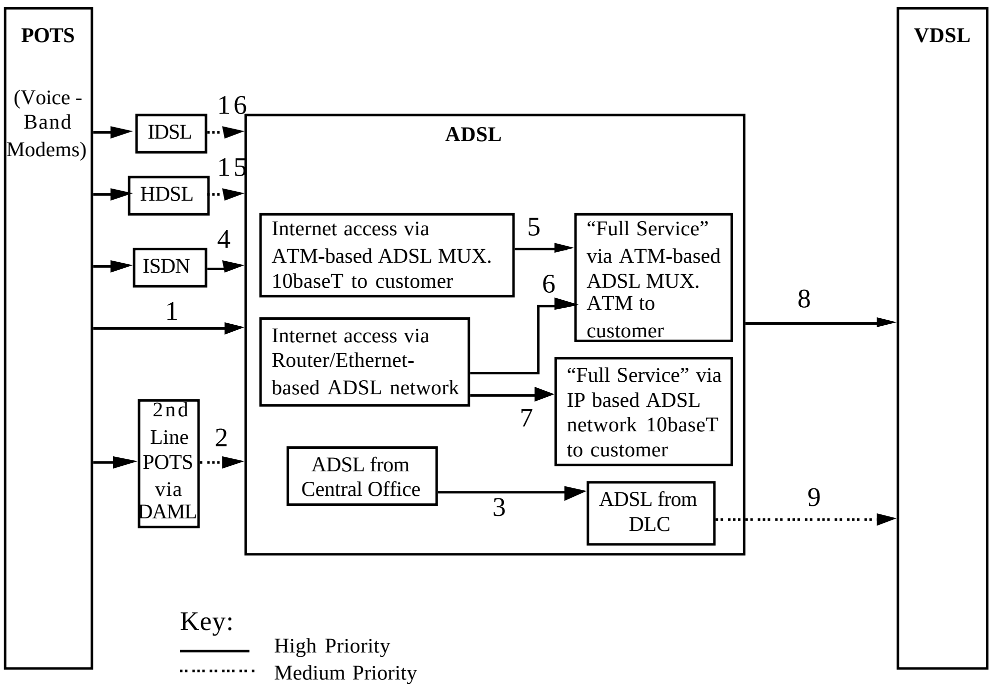

Figure 1 : Relationship of Migration Options

(Note : Only high and medium priorities shown, low priority migration options 10-14 omitted for clarity)

6. DESCRIPTION OF POTENTIAL MIGRATION PATHS

This section contains a description of each of the migration paths identified in Table 1. Each migration option is defined in terms of the starting network scenario and the target network scenario. The drivers that will initiate and influence the migration towards the target network scenario are discussed and the technical options to facilitate the network migration are then presented including their advantages and disadvantages. Hence the following sub-sections form the main focus of this working text.

6.1 INTERNET ACCESS : VOICEBAND MODEM TO ADSL MODEM

6.1.1 Starting Network Scenario

A customer is provided with Internet access via a POTS analogue connection. Through the use of voiceband analogue modems, a maximum bandwidth of 33 kbit/s exists (or possibly 56 kbit/s with the latest generation of asymmetric voiceband modems) thereby limiting the Internet services that can be provided.

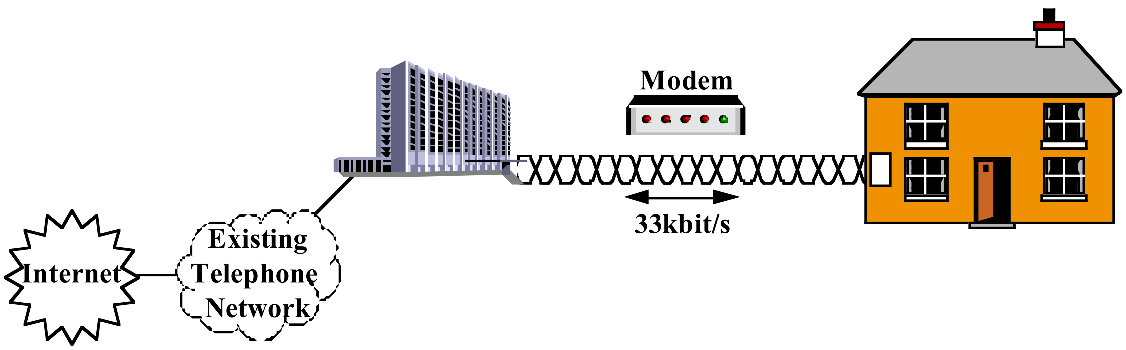

Figure 2 : Internet Access via Voiceband Modem

6.1.2 Target Network Scenario

A customer is provided with Internet access via an ADSL modem connection. Through the use of ADSL modems it is possible to provide a wide-range of both asymmetric and symmetric (SDSL) bandwidths that can deliver todayÕs Internet services, plus provide an evolutionary path to future, bandwidth-intensive services. The ADSL central office card could be connected to the internet backbone & ISP via either a DSLAM or Ethernet switch and router.

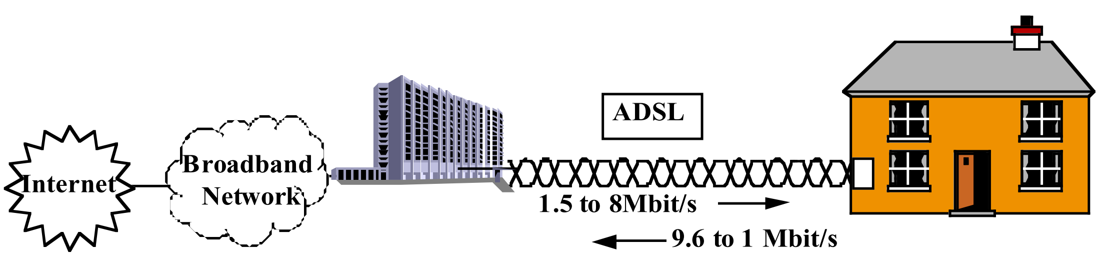

Figure 3 : Internet Access via ADSL

6.1.3 Drivers

The majority of Òmass-marketÓ residential access to the Internet is provided by analogue voiceband modems operating with a maximum data rate of 33 kbps. With the advent of the World Wide Web (WWW), a graphic-rich Internet service, bandwidth speed at both access points (client and server) have become a bottleneck. Now, the world wide web is often called the Òworld wide wait.Ó

The principal driver for the telco is to satisfy the need for high-speed Internet access which should eliminate the largest frustration associated with Internet access, the slow downstream transfer of graphical images from the server to the client (PC host).

A second driver for the telco is to move the Internet traffic, characterised by long holding times, off of the voice network which usually has short holding times. Many of the switches now carrying Internet traffic to the Internet Service Providers (ISPs) have been engineering with relatively high-ratio concentration stages and must be modified to reduce the concentration ratio to serve the increasing percentage of Internet traffic. ADSL deployment effectively moves this traffic from the voice network and places it on the more efficient packet or ATM network.

A third driver associated with going directly from analogue voiceband modems to ADSL modems is that an expensive ISDN upgrade is not required of the voiceband switch. ISDN is a network concept with a full multi-layer protocol stack of its own to support. This requires expensive hardware and software upgrades to the existing voiceband network elements. ADSL, on the other hand, is only a very high-speed modem and uses essentially the protocol stack of todayÕs existing data network, whether packet- or cell-based. This can dramatically reduce the complexity required to implement high-speed Internet access when the previous economics did not justify upgrading to ISDN capability.

A fourth driver is that from the telco subscriberÕs view it makes more sense to go directly from an analogue voiceband modem to an ADSL modem. With a maximum speed of 128 kbps, ISDN does not provide the bandwidth improvement to necessarily warrant the acquisition/wiring inconvenience. Both the telco and the ISP increase their charges to the subscriber, which may be too high to absorb for only a four-fold increase in bandwidth. ADSL modems will be the telcoÕs answer to cable modems, so there should be substantial competitive pressure to kept the monthly service tariffs of ADSL low.

A fifth driver appears when the telco also decides to become an ISP, which is beginning to happen at a rapid rate in the USA thanks to the passage of the recent Telecom bill. As more and more government-owned monopolies become privatised, these telcos would also look at providing many non-traditional ways of generating revenue. Becoming an ISP is one such avenue. There are many ISPs competing for the business. ADSL provides the telco with the ability to differentiate its offering by providing high-speed access along with local content and the ÒmirroringÓ of popular WWW sites for super fast response.

6.1.4 Options

6.1.4.1 Option 1: PC-based ATU-R

If the principal driver to ADSL deployment is high-speed Internet access, then an expedient method of providing this service to the telco subscriber is by providing an ADSL modem card that sits on the PC bus just as the majority of todayÕs analogue modems do. This reduces the complexity and wiring issues associated with multiple boxes at the subscriber premises. ADSL interoperability trials are important to this approach because this option would lead toward the subscriber owning the ADSL modem. The telco would usually not want to lease an ADSL modem to a subscriber when it is an internal PC card because they do not want to be liable for damaging the PC. One issue here is that the subscriberÕs initial voice-band access may be via a PCMCIA voiceband modem for ADSL is not a plug in replacement. If this is the case then the approach below of an external ADSL modem is more suitable.

6.1.4.2 Option 2: External ADSL Modem

The other option is to provide an external ADSL modem that connects to the PC via a 10BaseT Ethernet connection or direct computer serial link such as the universal serial bus (USB). This option may be more complex because the modem must be packaged in a housing and provides its own power supply. This option allows the option of being purchased by the telco subscriber and being leased, which is more similar to the cable modem deployment. In addition to the equipment being more expensive, the monthly fee may also be higher because a portion of the fee could include the leasing fee.

6.1.4.3 Option 3: Remote Access Router

There is a trend to have more than one computer in a home or small business. In this case, having an external remote access router providing multiple 10BaseT ports served by a single ADSL line would serve homes and small offices who want to share the cost of an ADSL line. The router would be connected between the ADSL remote unit ant the CPE.

6.1.5 References

1. ÒInternet Access - Voiceband Modem to ADSL ModemÓ, ADSLForum96-079, Tom Miller, Siemens, September 19th 1996, London Meeting.

6.2 Pair-gain Provided POTS to ADSL

6.2.1 Starting Network Scenario

Pair-gain or pair multiplier systems are used in many countries to provide a second POTS line over a single copper pair. These are called DAML systems in the USA and DACS in the UK. Many earlier systems were termed Òdata over voiceÓor 1+1 systems and used FDM to carry either an analogue or a 64 kbit/s digital telephony channel above the normal 4 kHz baseband voice channel. Recent versions of these systems use ISDN transmission devices in conjunction with additional analogue POTS interfaces to present two analogue POTS interfaces to the customer. Alternatively, the remote end of the system can be located at a pole-top or in a footway box to provide two separate dwellings with digitally derived telephony where both customers share the same physical copper connection from this remote unit back to the central office.

6.2.2 Target Network Scenario

The customer whose telephony is provided by a pairgain system now wants an ADSL delivered service (in addition to telephony).

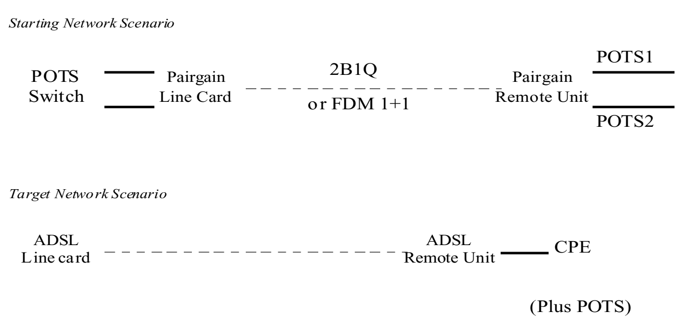

Figure 4 : Pairgain-served customer to ADSL

6.2.3 Drivers

Many telcos have deployed pairgain systems in order to save the cost of installing new copper cables. This is particularly prevalent in areas where duct space or cable capacity are full and only a small increase in capacity is required to meet new telephony demand but the forecasted growth in that area doesnÕt justify laying new ducts or cables. In addition, when some single occupancy buildings are converted into apartments or businessÕs, pairgain systems have proven an expedient way of meeting the demand for additional POTS lines. Now, some of these customers may want a service such as fast internet access or VoD which could potentially be delivered using ADSL.

6.2.4 Options

6.2.4.1 ADSL with a 64 kbit/s Derived POTS Channel

It would be possible to extract a 64 kbit/s channel from the digital payload of the ADSL (in both directions) in order to derive the capacity necessary to provide a second POTS channel (the first being delivered as normal analogue POTS in the voiceband below the frequencies used by ADSL). This would have to use the non-interleaved path through the ADSL transceivers to minimise latency. Even then the residual latency in some implementations may be too large for the required latency allocation to the access segment of an end to end voice connection. There are several problematic issues associated with this approach of a digitally derived POTS channel. The first is that in some countries there is an obligation on the telco to provide a life-line POTS service in the event of a power failure. Since ADSL is not line powered this presents a problem. It is likely that any attempt to line power ADSL (using currently permissible voltage levels) would reduce the range of ADSL to that of HDSL (12 kft, 3.7 km). Another issue is that many telcos are examining the use of ADSL to deliver ATM cells al the way to the customer. There appears to be a growing consensus that it is not desirable to try and mix ATM and STM channels on the same ADSL bearer. Hence to use such ATM based ADSL systems to derive a second POTS channel would necessitate the transport of POTS over ATM. This results in a 6 ms delay due to the buffering involved in encapsulating the POTS data stream into ATM cells. This can be overcome using proprietary composite cell techniques. Of course, if the original second POTS channel from the pairgain system was delivered into the same customerÕs house for use with their voice-band modem, they may not need a second POTS channel once they have ADSL.

6.2.4.2 Move pair-gain unit

When pairgain systems are used externally to deliver POTS to two different tenancies using the same Central Office line, they can be mounted at pole tops or in footway boxes. There is a physical limit on how many such systems can be co-located at these distribution points and many telcos will have guidelines for this working practise. for example, in some networks this final distribution point can feed ten to twenty customers and the maximum number of pole-top pairgain systems that can be co-located is say four. We need to consider the scenario where a customer whose single POTS line is provided by one of the channels of the pairgain system wishes to procure a service that could be delivered via ADSL. In such circumstances, the pairgain systems could be effectively ÒmovedÓ to supply a different (non-ADSL) customer from the distribution point simply be re-jumpering the connection at the pairgain system (distribution point and central office ends). The number of copper pairs between the distribution point and the central office remains unchanged. The ratio of total customers fed from a distribution point to those connected via pairgain systems is usually sufficient to allow the degree of freedom to implement the aforementioned process workaround.

6.2.4.3 Employ similar Techniques as for Simultaneous Delivery of ISDN and ADSL

Since many modern pairgain systems use the same 2B1Q transmission systems as Basic Rate ISDN, some of the techniques for delivering concurrent ISDN and ADSL to the same customer may be applicable in this network migration scenario. The issues related to delivering ISDN ÒunderÓ ADSL are described in the section covering ISDN to ADSL evolution.

6.2.4.4 Use an Additional Copper Pair

The obvious solution to the problem is to simply provide a second copper pair to the customer who has one or two POTS lines provided via a pairgain system and now wants an ADSL delivered service. At first sight this may seem a costly option, however two drivers may make this a sensible solution in certain areas. The first is that many telcos (particularly in the USA) are increasing their use of Digital Loop Carrier (DLC) systems. Their deployment may make some additional copper pairs available in some areas. Secondly, as telcos face more and more competition from operators using alternative technologies (e.g. radio, HFC etc.) then the inevitable loss of some customers to the competition will create some Òspare pairsÓ in the telcos network.

6.3 CO-BASED ADSL TO NGDLC-BASED ADSL

6.3.1 Starting Network Scenario

ADSL service(s) is (are) provided from CO-based equipment; that is, the ATU-C is located within the central office.

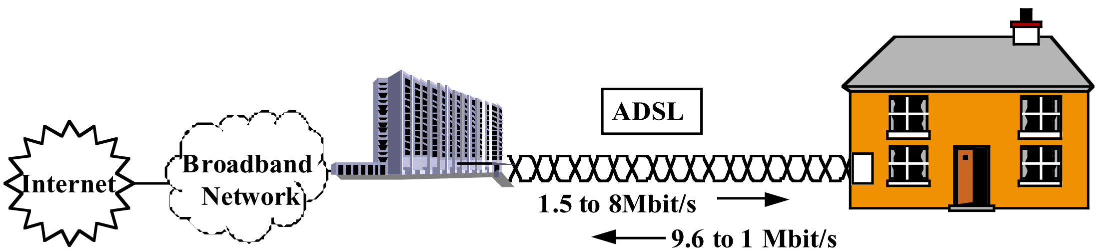

Figure 5 : Central Office/Exchange-Based ADSL

6.3.2 Target Network Scenario

ADSL service is provided from NGDLC-based equipment; that is, the ATU-C is located at the carrier serving area site of a next-generation digital loop carrier. The figure below shows ADSL access being provided by a Digital Subscriber Line Access Multiplexor (DSLAM) co-located with a Next Generation Digital Loop Carrier (NGDLC). Future products may combine the DSLAM. NGDLC and SDH/SONET Add/Drop Multiplexor (ADM) into one unit. In addition to using SDH/Sonet rings, the fibre feed may also use point to pint or PON topologies.

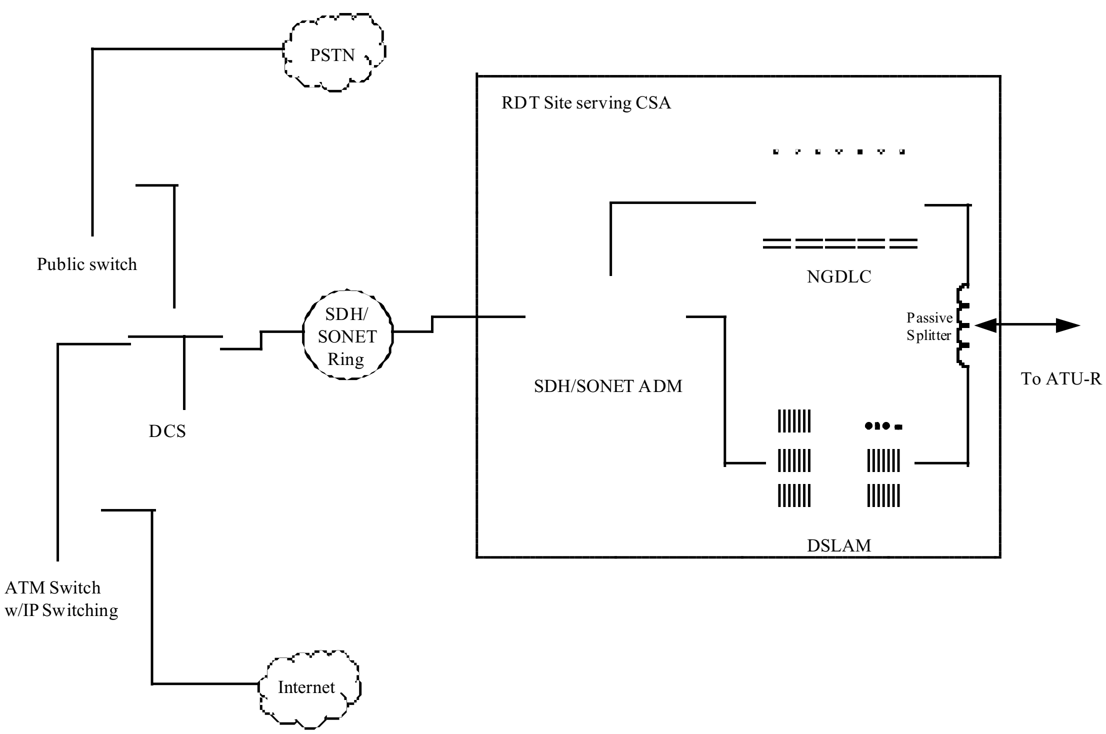

Figure 6 : ADSL Served from the RDT Site

6.3.3 Drivers

There are two principal drivers that will stimulate the migration of ADSL from being CO-based to NGDLC-based: 1) the performance improvement associated with the shorter loop length, and 2) the high-percentage of present subscribers being served by digital loop carriers.

The adoption of RADSL may mitigate driver 1 for high-speed Internet access and remote LAN access services by allowing an ADSL connection at a reduced performance level over long loop lengths, but future switched digital video services will want to enjoy the high-performance ADSL capability associated with loop lengths of 12 kft (3.7 km) or less. Also, if ADSL is to truly compete with cable modems, then ADSL must be capable of competing head-to-head with the effective bandwidth of cable modem.

In the USA, it is forecast that 45% of all access lines will be served by DLC systems by the year 2000. Some areas, for example, already have over 50% of access lines being served by DLCs. The previous migration to DLCs was motivated by the cost benefits provided by both pair gain (24/30 2-wire loops to one 4-wire T1/E1 connection) and a first-stage of concentration (usually 2:1). These figures provide a great incentive to develop NGDLC capable of delivering ADSL services to subscribers and aggregating the higher bandwidth through statistical multiplexing and connecting with the network via SONET/SDH.

6.3.4 Options

There are two physical options and two functional options associated with the migration of ADSL to the DLC site:

a) The two physical options would be for the ADSL-capable Remote Access Multiplexer (RAM) to either be co-located with a DLC or integrated into a NGDLC product. By moving the ADSL from the CO to the DLC location, the high transmission rate of the latest ADSL systems (8 to 12 Mbit/s) will be available to a higher percentage of customers. It will be important to understand the spectral compatibility issues in this scenario since some implementations of higher speed ADSL use greater bandwidth which could pose greater problems for compatibility with future VDSL systems. Power back-off may need to be implemented by the DLC based ADSL transmitter. For pedestal type locations the resulting use of the feeding fibreÕs bandwidth will be less efficient or economic. Also it should be noted that many remote terminals (RTs) are copper fed and not fibre and hence have less spare capacity compared to CEVs.

b) The two functional options refer to the RAM either being packet-mode based or ATM-based. The latter can be further divided into two sub-options; that is, ATM terminating at the RAM or ATM at the desktop. A recent RFP for such a device would indicate that providing ATM to the desktop (or set-top box) seems to be of interest to several operators.

6.3.5 References

1. RFP-96-07-MJM, Personal Computer/Data Network Access (PC/DNA), issued July 8, 1996 by the Joint Procurement Consortium of Ameritech, BellSouth Telecommunications, Pacific Bell, and SBC Communications.

2. ÒCO-Based ADSL to NGDLC-Based ADSLÓ ADSLForum96-080, Tom Miller, Siemens, September 19th 1996 (London Meeting).

6.4 ISDN TO ADSL FOR INTERNET ACCESS

6.4.1 Starting Network Scenario

A customer is provided with Internet access via a Basic Rate ISDN connection.

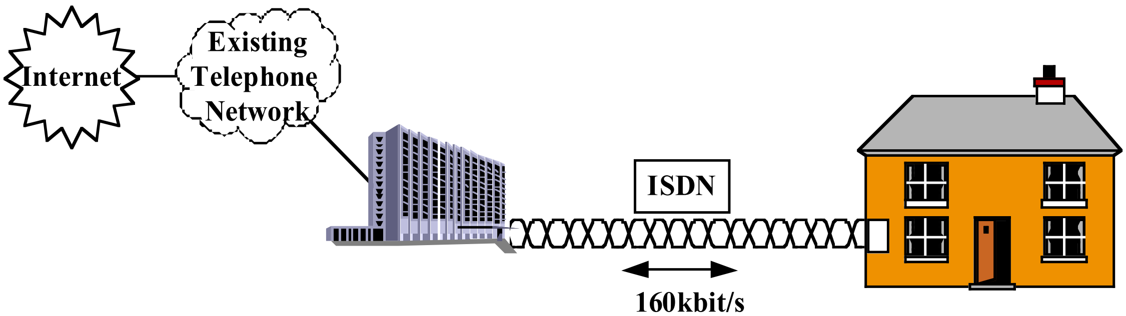

Figure 7 : ISDN-Based Internet Access

6.4.2 Target Network Scenario

The customer is to be given higher speed access to the Internet by use of an ADSL transmission system.

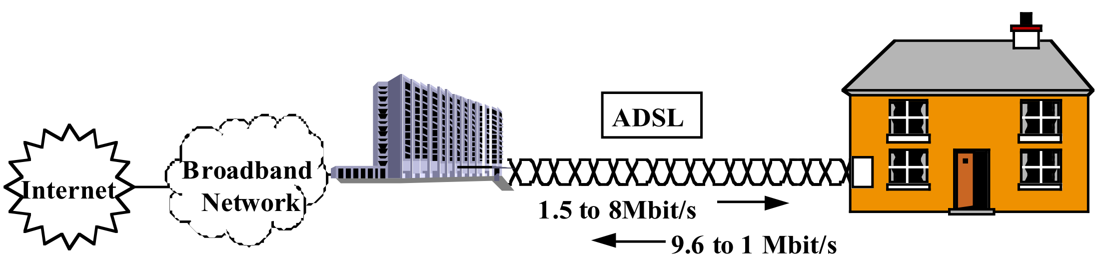

Figure 8 : ADSL-Based Internet Access

6.4.3 Drivers

The majority of Òmass marketÓ residential access to the internet is provided today by voiceband modems with a maximum data rate of around 28.8 kbit/s. Many telcos are increasingly selling internet access based upon Basic Rate ISDN. This can provide the customer with a data rate of around 128 kbit/s (with B channel bonding). The driver for the customer is the frustration many are feeling with the speed of downloading WWW pages that are rich in graphics. Many customers are switching off graphics display options just to make the internet usable. The driver for the telco to initially satisfy this thirst for bandwidth using ISDN is that ISDN is a mature established technology. It is proven in the network, there are many vendors offering interoperable equipment (if carefully selected) which has driven prices down. There are also a variety of other applications (e.g. PC based videoconferencing) that are available to exploit ISDN technology. Many telcos have both the transmission and switching infrastructure in place that enables them to offer this speed of digital access over their existing narrow-band network. However, it should be noted that this is not true of all telcos. Some who would have to provide an ISDN service using an overlay switch fabric may consider going straight to ADSL.

The desire for a telco to offer an ADSL-based Internet access upgrade to a customer is mainly driven by the fear of competition from cable modems. Many cable modem vendors are pitching their products as Òfaster than

ISDNÓ The expectation is that a telco could equal or better this competition by exploiting the higher data rates possible with ADSL. However, for most telcos this will require a new backbone network and switch infrastructure which is why ISDN is an easier first step. The driver for the customer to have even faster Internet access than ISDN is enhanced usability. Developments such as JAVA and software MPEG decoders will lead to increasingly video-rich content on servers. This will be further facilitated by real-time protocol developments. There is also an increasing trend for intranetworking and teleworking. This is leading telcos to consider technologies that allow a combination of Internet access and remote LAN access. The rationale for first fulfilling such a business requirement is that these early adopters have the deeper pockets necessary to kick start the ADSL market. This will help increase volumes to drive down costs to a level appropriate for the mass consumer market. This has been the case for ISDN where tariffs vary considerably around the world. In some countries, initial adoption of Basic Rate ISDN is almost exclusively by business customers. Packaged offerings based on ISDN (as with the Ameritech Home Professional Package, see http://www.ameritech.com/products/data/ahpp/) are available but for increased competitiveness these could potentially be evolved to ADSL transport. Some applications (including E-mail packages with a high degree of client-server interaction) only become usable away from the office LAN at ADSL speeds.

The issue for the telco is how to evolve a customer from ISDN to ADSL based Internet access with minimal cost and inconvenience to both telco and customer. One factor that helps smooth this transition is the fact that if a line has been conditioned already for ISDN (e.g. loading coils removed) then this aspect of deployment effort doesnÕt need to be repeated for ADSL. A particular issue of concern is what degree of backward compatibility is possible if the customer has already invested in ISDN specific CPE and other applications software (e.g. for videoconferencing/telephony) and wishes to continue to run such applications.

6.4.4 Options

6.4.4.1 Option 1 : Provide the same customer interface on ISDN and ADSL

This would enable a simple upgrade by replacing the ISDN NT1 with a remote ADSL unit that could physically plug into the existing CPE. The most obvious choice for a common interface is 10BaseT. Hence this option may only really viable if the telco is already providing ISDN with this interface or the customer is using an ISDN terminal adapter that provides this interface to the CPE. Many telcos provide the standard S-interface or an RS232 interface for onward connection to the CPE (PC or terminal adapter) This option would only solve the physical connection issue which may be sufficient for an Internet only service upgrade However, since ISDN is a dial up service, the impact on ADSL of signalling issues for other CPE/applications backward compatibility would have to be examined.

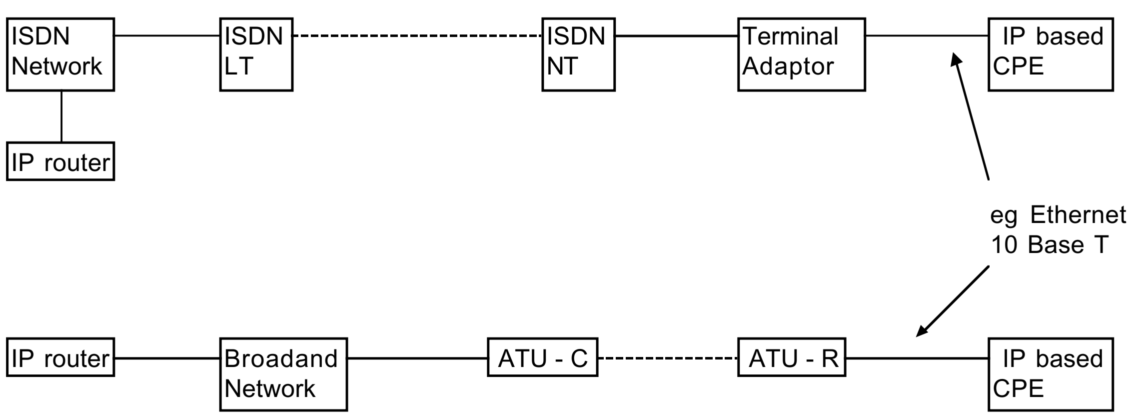

Figure 9 : Provide the same customer interface on ISDN and ADSL

6.4.4.2 Option 2 : ISDN or POTS under ADSL

This would enable both a legacy ISDN or POTS service and an ADSL service to be delivered over the same line. This requires the ADSL spectrum to be moved up from its current starting frequency to a higher starting frequency above the ISDN spectrum. In addition, the complexity of the splitter and the effect of reach on the ISDN service must also be taken into account and these factors could further increase the startin frequency of the ADSL system. This would reduce capacity left for the ADSL signal unless the entire ADSL signal is shifted to higher frequencies. Even then the ADSL signal would be more attenuated at the higher frequencies hence some significant ADSL range reduction could occur.

This option would result in wiring complexity at the central office end due to the fact that the customers line would need to be capable of onward connection to an ADSL and ISDN or POTS line card. Although this approach along with option 3 below are not currently catered for by the ADSL standard (unlike option 4), contributions to ETSI [1,2 & 3] propose further work in the standards bodies to develop such an option.

The Òuniversal splitterÓ[7] described above (ie. one capable of passing POTS or ISDN with a fixed spectral allocation for the ADSL signal) results in ADSL operation on POTS-only lines that is non-optimum. It is possible to conceive of an ADSL customer wiring configuration that has a separate splitter. In such a scenario it would be possible for some forms of ADSL modem to automatically adjust the spectral location of the ADSL data transmission in order to ÒadaptÓ to either a POTS only or ÒPOTS or ISDNÓ splitter (the latter having a wider low-pass filter bandwidth effectively blocking some of the lower frequency channel capacity available for ADSL transmission). This would give additional range for the POTS-only customers. However, as mentioned below, there are pilot tone issues to be resolved that would currently prevent standard compliant DMT modems from being used in this manner. In addition, mixing both POTS-only and ISDN-capable ADSL in the same network will lead to spectral compatibility, customer perception, provisioning and logistics issues [7].

The spectral compatibility problems arise due to a near-end crossstalk (NEXT) problem. POTS-only ADSL systems could start the ADSL signal at round 20 - 40 kHz whereas ISDN-capable splitters may start the ADSL signal at 170 kHz [7]. Hence the downstream band of the POTS-only modem will generate NEXT into the upstream band of the ISDN-capable modem. This problem of mixing POTS-onlty and ISDN-capable ADSL in the same network also applies to option 3 below.

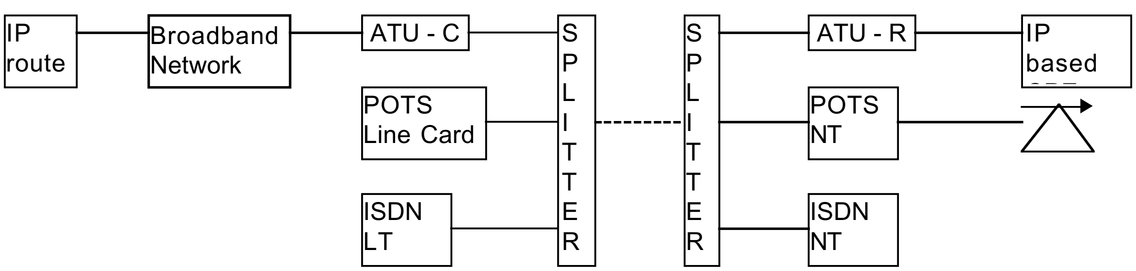

Figure 10: ISDN & POTS under ADSL

6.4.4.3 Option 3 : ISDN only under ADSL

a) A splitter designed only to pass ISDN and not POTS as well can be simpler since there are no ringing transients to cope with. However, this would then require the customer to have their telephony delivered digitally as part of the ISDN payload. This would already be the case if they were subscribing to ISDN Internet access and only had one copper pair entering their tenancy (i.e. ISDN wasnÕt on a 2nd line, the other which carried POTS). This is a true ISDN/ADSL hybrid. Exclusive use of this variant of ADSL equipment in a telcoÕs network would require that any customer wanting only ADSL Internet access must also be given ISDN in order to have telephony since they couldnÕt use existing analogue POTS simultaneously. Such a splitter design has been built [6] and this type of ADSL system could be of great interest to those countries with a high level of ISDN deployment (e.g. Germany, Holland, Switzerland etc.), especially where ISDN is used to provide telephony.

b) Range performance implication. ADSL spectra must be moved up from a 20 - 40 kHz lower band edge to start at over 140 kHz [7]. It is possible to design such a splitter that could locate the ADSL signal from above 140 kHz and above, this is sufficient to allow both 2B1Q and 4B3T ISDN to pass through it. The subsequent impact on ADSL range may be in the range 10-15% or a few hundred meters range reduction. Splitter design is simpler than option 2 since only ISDN impedances need to be matched, not POTS impedances which are complex in some operators networks. There could be a problem in that standardised DMT ADSL relies on a pilot tone at 76 kHz for timing synchronisation. Hence some silicon may not work in this configuration. It is likely that both ANSI compliant DMT designs and existing CAP designs would require some modification to accommodate the base-band ISDN. The proposals to ETSI [references 1,2,3 & 4] for future work on ADSL to examine the ideas presented in options 2 and 3 need to assess these issues.

Pair-gain systems are used in many countries to provide a second POTS line over a single copper pair. These are called DAML systems in the USA and DACS in the UK. Many of these systems use ISDN transmission devices in conjunction with additional analogue POTS interfaces to present two analogue POTS interfaces to the customer. An advantage of the aforementioned approach to operation of ADSL over ISDN is that it would be equally applicable to operating ADSL over such pair gain systems.

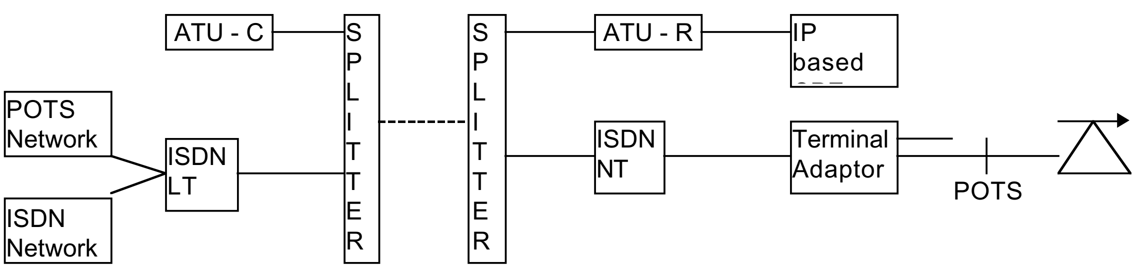

Figure 11 : ISDN only under ADSL

6.4.4.4 Option 4 : ISDN embedded in ADSL

a) No lifeline powering of ISDN transmission pipe and attached CPE as is normal for some telcos ISDN service (especially in Europe). But, lifeline telephony available from normal analogue POTS in base-band.

b) Need to switch off ADSL interleaver for acceptable delay. Latency reduces from around 20 ms to 2 ms for DMT & < 1ms for CAP. The 2ms residual delay is acceptable in terms of avoiding voice echo cancellation and may accord with some telco philosophies on end to end delay apportionment for overall voice network design. However, some ISDN specific standards say 1.25 ms.

c) Switching off interleaving to minimise delay will reduce impulsive noise immunity (on/off hook transients, ringing, access network & in-home impulse pick-up etc.). The resulting impact on range is very difficult to determine since impulse noise occurrence and magnitude varies considerably from line to line. However, some reduction in ADSL range & planning rule guidelines would almost certainly be required for acceptable BER performance of the ISDN portion of the ADSL payload. Note, the rest of the ADSL payload (used for VoD etc.) could still be routed through the interleaver independently. The ADSL standard accommodates programmability of trade-off between BER performance & latency for different data streams (e.g. ISDN & VoD) transported over the same ADSL line.

d) Embedding enough payload capacity for ISDN (160 kbit/s) wonÕt impact the range of an echo-cancelling ADSL system since upstream & downstream can overlap and hence both will have a lower band-edge of around 10 - 40 kHz (depending on splitter). It will have an impact on an FDM implementation since compared to say a VoD type 16 kbit/s return channel we now need an additional 160 kbit/s. Hence to make room for the ÒlatterÓ upstream channel, the downstream channel must be moved up from around 50 kHz lower band edge to 85-100 kHz. This reduces performance margin by around 2-3 dB (< 300 m on 0.5 mm cable). For internet access weÕd want more than a 16 kbit/s VoD type upstream rate anyway in order to get maximum throughput on a 1.5 to 2 Mbit/s downstream channel (given the way TCP/IP works, a 14:1 asymmetry ratio is believed to be adequate). Hence the additional return channel payload capacity needed for ISDN wouldnÕt be much different from that required in a good internet access 1.5 to 2 Mbit/s ADSL design. Thus the range loss due to incremental capacity requirement will not even be significant in an FDM implementation if the upstream capacity is shared for internet access & ISDN. However, if ISDN and fast internet access are required to operate simultaneously, dedicated upstream capacity is needed for the ISDN and so the capacity for upstream internet communications is additional. This could have a significant impact on reach in an FDM implementation but wonÕt affect an echo cancelling implementation.

e) This scenario offers both an analogue POTS baseband voice path and potentially a digital ISDN derived voice-channel (i.e. a 2nd ÒPOTS lineÓ). If a 2nd voice channel isnÕt required then potentially the analogue baseband POTS channel could be relinquished to yield additional capacity-rich spectra for ADSL transmission. The customers telephony would be provided by a digitally derived 64 kbit/s channel within the ISDN portion of the ADSL transmission payload. Some ADSL implementations may then enable the ADSL spectra to be ÒshiftedÓ down into the baseband nearer to DC where there is less signal attenuation. This would enable the ADSL transmission system to recover some or all of the range loss incurred in carrying the additional ISDN payload. This would also avoid the need for a POTS splitter. However, doing this would lose any lifeline POTS capability.

f) Additional interfaces will be required at the customer end. In Europe this would require an S-interface chip (plus glue logic, PCB re-work, connector costs and subsequent impact on production costs). To do the equivalent in the USA would require a more expensive U-interface chip due to the wires only interface.

g) Appropriate interfaces will be required at the central office end. One option is to extract the ISDN data from the ADSL payload, put it through an ISDN U interface chip so that it can then talk to an ISDN line card embedded in the narrow-band switch. This could be messy and costly. The alternative is to extract the ISDN payload from several ADSL linecards and multiplex them into a 1.5 or 2 Mbit/s stream for a multiplexed interface (e.g. V5.1) into the telephony switch.

h) The above scenarios have discussed ADSL as a step beyond ISDN. ADSL could also be envisaged as a step towards VDSL. In this scenario the ADSL is more likely to be an ATM to the home solution in order to provide a smooth migration and complimentary deployment capability. ISDN couldnÕt then be embedded in the ADSL due to ATM buffering/packetisation delays. The alternative is to channelise the ADSL to have ATM and non-ATM paths. This could be very complex and expensive.

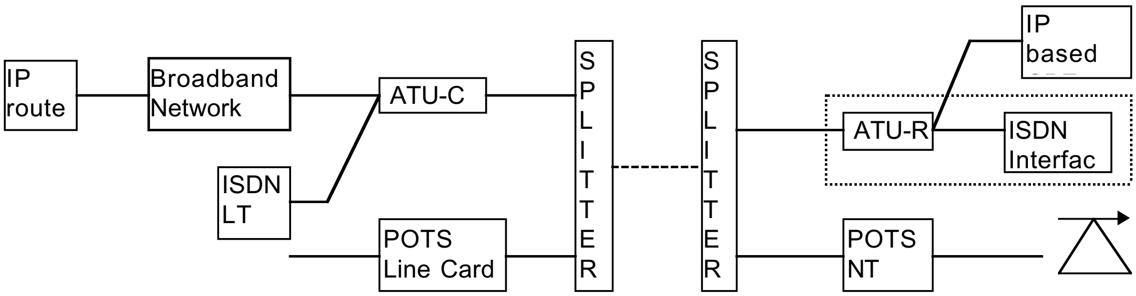

Figure 12: ISDN embedded in ADSL

6.4.4.5 Option 5 : Don't try & deliver ISDN & ADSL on the same pair.

a) This option avoids a "special"[3] hybrid ISDN/ADSL solution by using a second copper pair if joint ISDN and ADSL take-up is expected to be minimal. Why load the costs of the ADSL solution for all ADSL Internet customers if say < 5% want both ADSL and ISDN capability? A second pair, provision of a terminal adapter or offering the customer a CPE swap/upgrade deal may be cheaper overall to satisfy those few customers wanting simultaneous ISDN and ADSL. This latter idea assumes they were using ISDN CPE only for internet access. If the customer was also using it for switched access (using ISDN signalling) to their work LAN for teleworking, how does ADSL replace this capability ? So the telco may need to provide a second pair for such customers. Will there be many ? Provision of a 2nd pair whilst costly may only be required for a few customers. In addition, it should be noted that in countries where the incumbent telco faces increasing competition from other network providers using non-copper media (such as radio or fibre-coax), any loss of customers to the competition will increase the availability of spare pairs. Apart from avoiding any impact on ADSL equipment designs, this option would also not require the complex central office wiring necessary to connect a customers ADSL line to ISDN line cards, POTS line cards AND a broadband connection to an Internet service provider. It would also avoid the problem of fault handling on a copper line potentially carrying three services (via POTS, ISDN & ADSL) with associated impact on test equipment and telco operational processes.

b) Do we really need this technology evolution step when in many countries ISDN deployment levels are low or to business customers only. In such territories it may be sensible to skip the ISDN Internet access step for mass-market/residential fast Internet access. The option of skipping the ISDN step would depend on the ready availability of a broadband switching and backbone network that could be used in conjunction with ADSL. The issue is how much future ISDN revenue is a telco already relying on to happen and how much of this is expected from the residential sector. Could this be replaced by ADSL revenue and what are the business/residential cross product line dependencies for ISDN ?

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[3] It will be a "special" variant of ADSL until standards (official or de-facto) and telco demand lead to widespread development and deployment of such ADSL variants as were discussed in options 2, 3 and 4

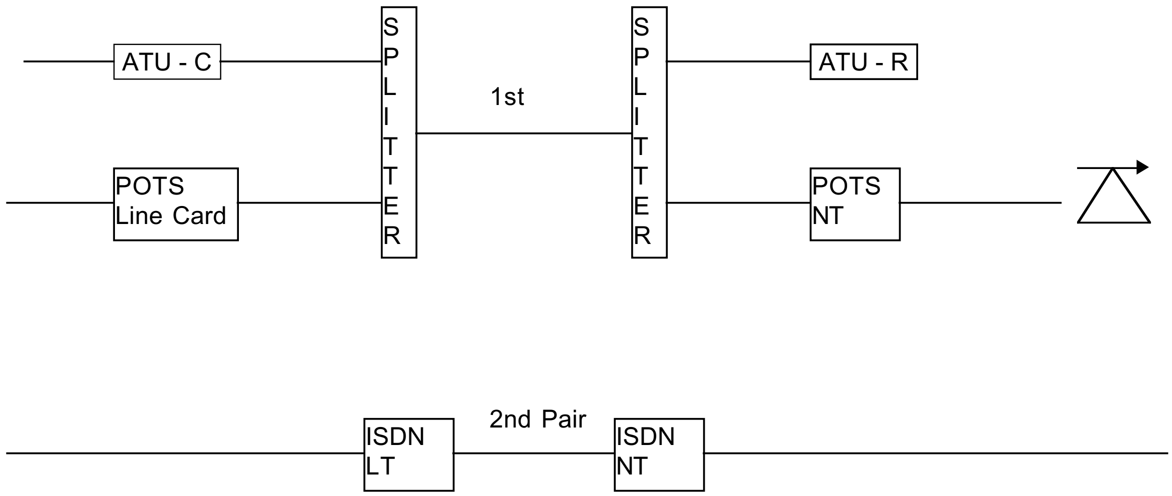

Figure 13 : ISDN and ADSL delivered on separate pairs

6.4.5 References

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2. ETSI Contribution 96/2T/10, ÒADSL Future WorkÓ Motorola, Bernard Dugerdil.

3. ETSI Contribution 96/2/T15, ÒADSL over ISDN BRAÓ Ericsson Austria AG, Franz Haberl.

4. ETSI Contribution, 96/2/T16, ÒADSL ISDN FilterÓ Ericsson Austria AG, Mr. Etlinger.

5. ÒISDN to ADSL for Internet AccessÓ ADSLForum96-083, Gavin Young, BT, September 19th 1998 (London Meeting).

6. ETSI Contribution, 97 Tel Aviv meeting, Orckit.

7. ADSL-Forum/97-139, ÒOn the Migration Path from ISDN to ADSLÓ Boaz Rippin, Orckit, September 16th 1997 (Brussels meeting).

6.5 ADSL IN AN ATM NETWORK : FROM INTERNET ONLY TO FULL SERVICE

6.5.1 Starting Network Scenario

A customer is provided with an ADSL transmission system that connects into an ATM backbone network via an access multiplexor with an ATM network interface (known as a ÒDSLAMÓ - Digital Subscriber Loop Access Multiplexor). However, the ADSL remote unit presents an Ethernet 10baseT interface to the CPE. The system is aimed mainly at use for internet access and remote teleworking/LAN access. The ADSL remote unit may include integrated bridge/router functionality.

Somewhere in this access connection there is functionality to perform protocol conversion between that used at the Ethernet 10BaseT interface and that used in the ATM. The ADSL central office equipment connects to the ATM switched network via an SDH/Sonet interface carrying ATM traffic for multiple users. This interface point could conform to VB5.1 or VB5.2 once it is standardised. In some implementations, the multiplexor may perform statistical multiplexing and ATM Peak Cell Rate (PCR) policing to ensure that some customers canÕt violate their traffic contract at the expense of other customers. This would add to the complexity of the multiplexor and could require additional buffering. Management of this traffic issue is even more important if rate adaptive ADSL is used since there is potential for short-range customers to use higher data rates over the ADSL than other customers. At the remote end, the data is presented on a standard fixed rate 10BaseT ethernet interface.

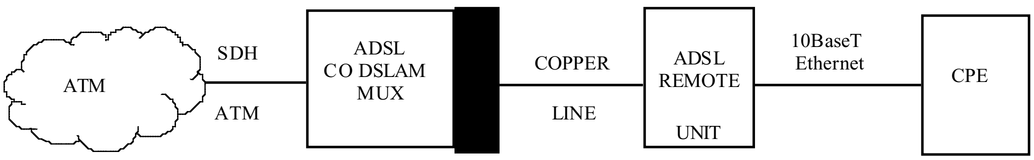

Figure 14 : ATM over ADSL for Internet Access

The attractions of this scenario are that the CPE does not have to perform ATM adaptation and the ADSL remote unit could be directly connected to the Ethernet card in a PC. The disadvantages are that the ADSL or multiplexor equipment has to perform AAL and perhaps signalling protocol conversion functionality which adds complexity. It also reduces the flexibility of this ADSL access equipment since it now contains a service specific element in the access equipment. Another potential disadvantage to the telco is that it puts the same AAL and protocol conversion functionality requirements on any fibre and radio access equipment that the telco may wish to use interchangeably to more economically or conveniently deliver the same service. The protocol conversion will undoubtedly complicate system integration and testing. It is worth noting that whilst Ethernet cards for PCs are readily available, these mostly reside in business PCs connected to corporate LANs. Most residential users would still have to buy this card for their machine since the dominant communications connection is via a voiceband modem or for a minority, ISDN.

6.5.2 Target Network Scenario

The customer is to be provided with an ADSL transmission system that presents an ATM interface to their CPE thus transporting ATM cells end to end over the access link. A wide variety of services are provided over this network.

In this scenario ADSL is acting purely as a transparent pipe, with some cell routing in the access multiplexor to direct traffic to the appropriate line card. The access multiplexor acts as a PVC cross-connect and with the implementation of suitable signalling to an ATM switch higher up in the network, this approach would present a B-ISDN connection to the customer [1]. The ADSL exchange equipment connects to the ATM switched network via an SDH or Sonet interface carrying ATM traffic for many users. Cell routing is performed on the traffic to direct it to the appropriate line card i.e. cell delineation, demultiplexing and rate decoupling from the network to the ADSL line. The individual customer's cell stream is presented on an ATM physical layer interface (such as a 25Mbit/s 4bit/5bit encoded NRZI ATM Forum interface) at the ADSL remote unit.

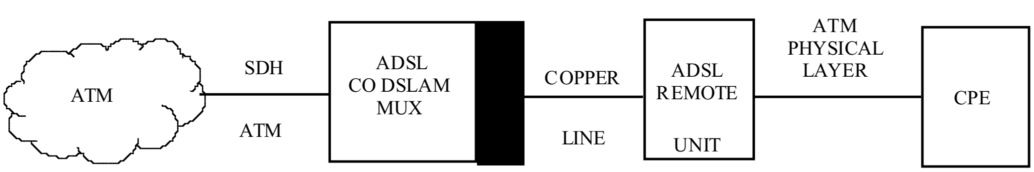

Figure 15 : ATM over ADSL for a Multi-Service Access Network

The attractions of this network scenario are that it is relatively simple as far as the ADSL is concerned and would result in an ADSL system that is compatible with and complimentary to a longer term ATM access delivery technology such as FTTN/VDSL. No signalling protocol conversion is required in the access equipment and there are no service specific elements in the access equipment. It could present a simple open standard interface to the CPE with signalling presented on the same wires and interface separated out by cell headers. It could also facilitate simple integrated end to end management all the way to the CPE including alarm surveillance and connectivity verification via ATM OAM cell flows. Several vendors are already developing PC cards and set-top boxes that would constitute the CPE that could be connected to this network.

The disadvantages are that the CPE must perform the ATM AAL function, and implement Q.2931 call control (i.e. the B-ISDN terminal adapter function). This could for example drain some of a PCÕs available processing power. Until ATM switches implementing Q.2931 are widely deployed, nailed-up or permanent VCÕs (PVCÕs) are necessary in early manifestations of this architecture until switched VCs (SVCs) are implemented. In this latter scenario the access multiplexor could be purely an ATM cross connect with signalling dialogue occurring between the CPE and ATM switch. Hence SVCs would be supported by ÒtunnellingÓ signalling messages through to a UNI at the ATM switch. Alternatively the DSLAM could evolve to an ATM edge switch presenting a NNI to the ATM switch. Another issue to resolve in this Òpure ATMÓ architecture is flow control and the dimensioning (and location) of suitable buffers for traffic shaping. Some of todays ATM NIC cards that would reside in a PC may just burst out the data.

6.5.3 Drivers

This section describes the commercial and technical influences that could cause a telco to deploy the access network for internet access described as the starting network scenario above and then want to migrate it towards the end-to-end ATM network described as the target network scenario.

Initial trials of ADSL were focused very much on interactive services aimed at the mass residential market (VoD, home shopping, home banking etc.). However, non of these particular services is widely regarded as a Òkiller applicationÓ in its own right. It is generally considered that ultimately a package of such services will be needed to be competitive. However, in the short term, high-speed internet access has become thought of by many as the most likely single service that may make a viable business on its own. Much of the telco interest in using ADSL for such a service is to counter the threat of cable modems. Cable modems will enable cable companies to offer a high-speed internet access service over HFC networks. ADSL is seen by many as the most straightforward telco response to offer an equivalent or better service over the twisted copper-pair telephony network.

The development of cable modems is progressing rapidly and so there is great interest from telcos in making a high-speed internet access data service the first focus of any ADSL deployment. Many PCs are (or can be) equipped with an Ethernet card with a 10BaseT interface for Ònetwork connectionÓ. Such cards are mature products and are widely and economically available. Hence adding this sort of interface to the remote ADSL equipment will enable many customers to directly plug in their PCÕs (or perhaps Network Computers, NCs in the near future) without additional expense. This is more true of the business PC environment since far fewer home PCs today contain an Ethernet card. Another point to note is the huge growth in laptop and notebook PCs. PCMCIA Ethernet cards are available for these as a neat plug-in option. The equivalent developments for an ATM25 interface are not as mature. A benefit of focusing on internet access for initial ADSL deployment is that it targets a customer base more likely to be early adopters of such new technology and encompasses business applications such as teleworking, remote LAN access and intranetworking. This sector of the market is more likely to pay a little extra for what will be a premium service in the early days until equipment prices have reached a mature base level. This is unlike a mass residential service such as VoD which will be benchmarked against the local video store from day one.

The data WANs that make up a large proportion of todays internet backbone use technologies such as Frame Relay (FR) and Switched Multi-megabit Data Service (SMDS). However, increasingly telcos are looking to deploy high-speed ATM networks to transport internet traffic simultaneously with many other kinds of services. This has resulted in a lot of interest in ADSL or xDSL access multiplexors (DSLAMs) that can connect to such an ATM network. Hence the combination of several drivers result in the starting network scenario described earlier. These drivers are : growth of ATM backbone networks and subsequent acceptance of ATM interconnection by internet service providers (ISPs), perceived need for high-speed internet access, threat of competition from cable modems and availability of cost-effective Ethernet cards for PCs.

From the above it is clear why the current focus for high-speed access networks is internet access. However, most telcos aspire to evolve to a Òfull-serviceÓ network at some time in the future. Some believe that such full service capabilities may evolve from the internet itself with the development of real-time protocols, bandwidth reservation (RSVP) for improved QoS etc. Others believe that the ultimate flexible, multi-service network must be based on ATM. The migration scenario considered in this document assumes the latter vision and hence part of the migration strategy must consider how internet access (using TCP/IP) is supported over an ATM network. ATM cards already exist for PCs and set-top boxes and cable modem vendors are also addressing the same development and migration issues involving Ethernet and ATM customer interfaces. An ADSL system that transports ATM cells into some form of home network to deliver a mixture of services such as internet access, VoD, broadcast TV etc. is technically feasible today. A combination of maturing equipment, declining prices, increasing availability and installed volume of ATM equipment will determine how rapidly this Òpure ATMÓnetwork vision is reached. The next section describes some of the options available in evolving towards this vision.

6.5.4 Options

In order to facilitate the afore-mentioned evolution, the starting network scenario needs to include ATM adaptation at some point in the access network. There are three possibilities for where this functionality could be located : At the customer premises (in the remote ADSL unit or a terminal adapter) in a processor within the access multiplexor supporting multiple lines or on each ADSL line-card within the multiplexor. These will now be discussed in more detail.

6.5.4.1 Option 1 : ATM Adaptation at the Customer-End Equipment

ATM cells from the backbone network are routed to the appropriate multiplexor line card and on to the ADSL remote unit. The ATM AAL and protocol conversion are carried out by a converter circuit which may be integrated into the ADSL remote unit or could even be housed in a separate co-located box or plug on module in the manner of a terminal adapter. Generally, additional boxes are not desirable. This converter functionality can be thought of as a B-ISDN terminal adapter. The data is presented to the customer on a standard fixed rate Ethernet 10BaseT interface.

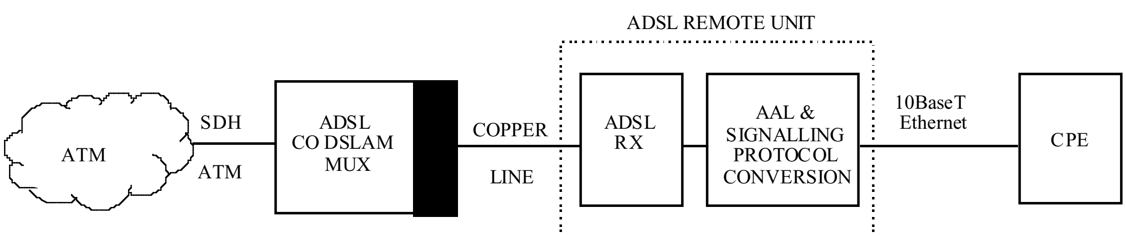

Figure 16 : ATM to 10BaseT Conversion in the Remote ADSL Unit

An advantage of this scenario is that the (in-built) ÒterminaI adapterÓfunctionality could be common to copper, radio & fibre delivery mechanisms. Although this results in a service specific (Ethernet) element in the access equipment, it is only at the network periphery and so an upgrade to full ATM delivery could be as simple as changing the remote unit. If the ATM protocol conversion is placed in a separate terminal adapter box, upgrade could simply involve removing this box. However, in some countries this may raise regulatory complications with respect to the boundary between network and customer owned equipment.

6.5.4.2 Option 2 : ATM Adaptation by a Shared Processor in the Access Multiplexor

This option has the advantage over option 1 that the costs of the processor, SAR function and buffering needed for ATM conversion can be shared among several customers. Unlike option 1 where migration simply required swapping a remote unit, upgrade from this scenario could requires a significant upgrade to the multiplexor in addition to changing the remote ADSL unit. Hence, it may not be simple to migrate this option to the target network scenario unless a significant amount of this functionality is implemented in software.

6.5.4.3 Option 3 : ATM Adaptation on Each Multiplexor ADSL Line Card

This approach has the similar per line ATM adaptation functionality (& hence complexity) as option 1. However, like option 2, the problem is with migration to the target ÒATM all the wayÓ scenario. Such an upgrade could now involve changing out both the multiplexor ADSL line card and the ADSL remote unit.

For any of the above network migration strategies to be successful, the target network scenario of ATM all the way to the CPE must still be capable of delivering TCP/IP internet access since in the above scenario this is the Òlegacy serviceÓ that initiated the deployment of ADSL and will probably still be a significant service in the portfolio to be delivered by the ATM ADSL Òfull serviceÓ network. There are several options for supporting TCP/IP in an ATM network and these will now be discussed in more detail.

6.5.4.4 Option 4 : IP over ATM (IPOA)

Classical IP over ATM, as defined by the IETFÕs RFC 1577, predates LANE and already has a significant installed base. Strictly this will not provide a general ÒEthernetÓ service to the user, but a useful set of network services including World Wide Web for example, can be delivered using IP. This is a Layer 3 routing protocol, unlike LANE which provides Layer 2 bridging only.

Thus IP can be implemented directly over ATM [2] in which case ATM is used to connect local LAN segments and IP end stations and routers instead of ethernet. This approach is applicable only to a single IP sub-net with no multicasting. The ATM network will in general consist of a number of Logical IP Subnets (LISs), and each Ethernet segment will also be a separate LIS. The various LISs are interconnected by routers, hence in this scenario the ATU-R would be a small router, providing IP routing between its ATM (ADSL) and Ethernet ports. In summary, each ATM LIS has a server for ATM Address Resolution Protocol (ATMARP, explained below) which provides translation between IP addresses and ATM E164 addresses. Ethernet segments operate Address Resolution Protocol (ARP) in a distributed manner using broadcasts to translate IP to Ethernet MAC addresses. If the ATU-R receives a packet from the Ethernet, it will consult a table to determine the IP address of the next hop router to forward the packet to, and which of its ports to use. Assuming the next hop is via the ATM interface, the ATU-R then needs to know the ATM address of the next hop router. It gets this information by consulting the ATMARP server of the ATM LIS to which it is connected using protocols defined by RFC1577. The ATU-R would then use UNI signalling to establish a connection to the next hop router. If the ATU-R had a pre-existing VPI/VCI to the next hop router, this could be determined at the first stage, in which case the ATMARP request and VC setup would not be needed. The ATU-R needs to hold a table of the MAC and IP addresses of all the stations on the home Ethernet which require IP service. It must register the IP addresses it provides access to with the ATMARP server of its Logical IP subnet (LIS).

Hosts from different IP sub-nets must communicate via an intermediate IP router even when a direct VC connection over the ATM network between the two is possible. Hence this approach has limitations. Each separate network administration unit configures its hosts and routers within a closed logical IP subnetwork (LIS) which is effectively the equivalent of a LAN. Each LIS operates and communicates independently of other LISs on the same ATM network. All members of the LIS have the same IP network/subnetwork number and address mask. Communication to hosts outside the local LIS must go via the IP router, which is configured as a member of one or more LISs. This may have implications for the partitioning of the LIS and location of the router within the target ADSL architecture. For example, would it be practical to have all customers within a Central Office area form part of a single LIS. Alternatively, a business or advanced residential user with multiple CPE connected to the ADSL remote unit via a hub could form a LIS.

IP addresses are often chosen by the customer where as the physical addresses (data equivalent of the telephone number) are often assigned by the telco. ATM assigns each end terminal an address which must be used when establishing a virtual circuit. An ATM physical address is larger than an IP address and so canÕt be encoded within the IP address to give static address ÒbindingÓ (linking an IP address to an ATM hardware address). Given that the target ADSL architecture is aimed at deployment in large telco networks and not smaller private networks, static address binding is not viable due to the amount of IP addresses that would be required for a large service roll-out (say several tens or hundreds of thousands of IP addresses). Creating and maintaining the address tables would be unmanageable.

Traditional LANs such as Ethernet use ARP (the address resolution protocol) for dynamic address resolution to find the hardware address of another machine [9]. It does this by broadcasting on the LAN an ARP request containing the IP address of the machine for which the hardware address is required. All machines on the LAN receive this and the one which matches the IP address sends back its hardware address so that data communication can commence. For dynamic address allocation where an IP address is not permanently Òhard-wiredÓ to a hardware address, at start-up a host needs to contact a server to be given its IP address. RARP (reverse ARP) is used for this purpose. On boot-up the computer would broadcast a RARP request which contains its hardware address. The server on the LAN would then look to its mapping table and send back an IP address to correspond to the hardware address. From the descriptions above it is clear that both ARP and RARP rely on broadcasting onto the LAN. ATM however does not support hardware broadcast in this sense and so the ARP and RARP methods canÕt be used to bind IP addresses on ATM networks. ATM PVCs complicate address binding. Since the PVCs are configured manually, a host only knows the VCI/VPI pair. Software on the host may not know the IP address or ATM hardware address of the remote endpoint. Hence any IP to ATM hardware address binding protocol must provide for the identification of a remote computer connected over a PVC as well as the dynamic creation of SVCs to known destinations. SVCs further complicate address binding because when setting up the VC, the destination IP address needs to be mapped to an ATM hardware end point. Also, the destination IP address needs to be mapped to the VPI/VCI pair for the circuit to be used each time data is sent over the ATM network.

ATMARP as the address discovery protocol to resolve between IP addresses and ATM addresses. ATMARP is the same as classical ARP in a LAN environment, but modified to exist in an ATM LIS. There is no protocol to associate the CPE with the default gateway and so each host is equipped at set-up with the address of the ATMARP server, rather than broadcast a request as in shared medium LANs. Hence this approach requires ARP server functionality at the ATM switch which isnÕt widely implemented yet. When hosts apply to an ATMARP server for the ATM address of the destination host, the ATMARP server consults its tables and returns a ATMARP reply containing the ATM address required. Each host in the LIS must register with the server by supplying its IP address and ATM address to the server. The ATMARP server uses ATMARP requests to update its tables. Each client in the LIS is also responsible for refreshing its ATMARP information with the server at regular intervals since the address binding is aged and after a time-out must be re-validated (done by opening a VC to the server and exchanging the ATMARP set-up packets) or discarded. For PVCs, Inverse ATMARP is used to discover the ATM and IP address of remote computers.

ATMARP packets and IP datagrams are encoded using AAL5 and encapsulated using LLC/SNAP encapsulation (see also [3]). ÒMultiprotocol encapsulation over ATM adaptation layer 5Ó is described in detail in RFC 1483. It provides for an alternative method of encapsulation which is more suitable for ATM switched virtual circuits and uses the signalling protocols of B-ISDN. The IP over ATM working group of the IETF issued RFC 1755 ÒATM signalling support for IP over ATMÓ to act as an implementation guide intended to foster interoperability among RFC 1577, RFC 1483 and UNI ATM signalling.

In current IP implementations, communications between nodes on different LISs, even if these are on the same ATM network, must pass through a router every time a LIS boundary is crossed . This is inefficient because there can be a chain of routers, each of which is a potential bottleneck, and it is not possible to have a single ATM connection between source and destination with a specified QOS.

Other concerns are whether IP alone can support a sufficiently rich set of services, and the cost and complexity of the router function required in the ATU-R. Also, the address space of the current version IPv4 is running out.

A new version, IPv6, has been developed which expands the address space. There are also new techniques such as Next Hop Resolution Protocol (NHRP) which enable cut-through routing, avoiding the need for traffic to go through multiple IP routers within the ATM network with consequent throughput and latency limitations. Also under development is Real Time Protocol (RTP) for transfer of real time data such as audio or video over IP networks.

The IETF is working on a new protocol called ÒNext Hop Resolution ProtocolÓ (NHRP). The goal is to enable a host to bypass some or all of the routers between source and destination hosts by establishing a direct connection through the ATM switches. NHRP makes routing databases within the ATM network accessible for virtual circuit call setup. An ATM address resolution request is passed from NHRP server to NHRP server until the ATM address for the destination IP address, or that of the router at the exit of the ATM network is discovered. There may be multiple LISs within the ATM network , each with an NHRP server, in which case this process will cross LIS boundaries using multiple hops in much the same way as the classical approach, except that only routing information is transported. Once the ATM address is determined, it is passed back to the requester, along the same route, allowing the intermediate servers to learn the route. When the requester receives the ATM address of the destination, it can establish a direct ATM circuit to the destination using ATM signalling. This is a cut-through route which bypasses any LIS boundaries within the ATM network, hence it avoids router bottlenecks and can have a defined ATM QOS. In some circumstances, traffic may still have to pass through routers however, for example when crossing administrative boundaries or firewalls, or if the destination is not on the ATM network.

The main problem with the IP over ATM approach is the lack of an inherent protocol to dynamically allocate IP addresses. It has been described above how it is impractical for each customer in the ADSL access architecture to have a static IP address pre-allocated. Anyone wishing to sell such a service is unlikely to be able to get more than a thousand or so addresses from the IPV4 administrators. Hence this presents a serious scaling issue. It may be possible to device a proxy architecture that employs a PVC from the CPE or ADSL remote unit to a DHCP or BootP server which then allocates the IP addresses dynamically. The problem of the remote ADSL/CPE sending out broadcasts to address allocation servers could potentially be overcome by using a router (in the central office or higher up the network) to cache the broadcast and the VC it came in on and then send out a directed request to a pre-configured DHCP server. The returning response can then be tied back to the correct customer VC and passed to the ADSL remote unit and CPE.

Classical IP over ATM is tailored to the transport of just IP traffic and hence is simpler than LAN emulation and generates less overhead. ATM is not hidden from the higher layers as in LAN emulation and so IP over ATM can take advantage of ATMÕs features such as ability to specify quality of service, cell delay, maximum PDU size (which can exceed 9000 bytes). However, this does mean that to access a device with a legacy LAN one must go through a bridge or router.

The following is an overview of the functions required at the ATU-R, in the Network, and at the Service Provider [11].

In the ATU-R:

- Ethernet PHY
- Ethernet MAC
- IP ARP - provides IP address resolution to the Ethernet (returns the ATU-RÕs MAC address for access to network services, which it recognises by the requested subnet address being different from that of the local LAN)
- Routing function - provides routing of IP packets to Ethernet MAC frames (i.e. the ATU-R is a small router, it needs a table of the MAC and IP addresses of connected CPE)
- Logical IP Subnet Client - operates IP over ATM protocols on the network interface
- ATM network interface (includes UNI signalling)

In the Network:

- ATMARP Servers - provide address translation between IP and ATM E164 addresses.
- IP routers - handle communications between Logical IP Subnets

At the Service Provider:

- IP-based service
- Logical IP Subnet Client
- ATM network interface

6.5.4.5 Option 5 : LAN Emulation (LANE)

The starting network scenario described earlier effectively requires some form of bridging functionality to connect the customer end ÒLAN segmentsÓ to the ATM network. These bridges can also perform routing functions at the network layer. LAN emulation (LANE) was developed by the ATM Forum [5] to support physical LAN interconnection. The aim of LANE is to make the ATM network invisible to legacy LANs making it possible to benefit from the performance enhancements of ATM without the expense of hardware or software changes to the end devices. This protocol provides an encapsulation mechanism for transporting IEEE 802.3 Ethernet (or token ring) frames across the ATM network using AAL5. It also specifies a set of service protocols that make the ATM network (which is point to point connection oriented using switches) emulate a traditional LAN (which is broadcast or point to multipoint connectionless oriented using bridges and routers) [6 & 7]. LANE is a general solution that allows any protocol defined to run over Ethernet or token ring to work transparently in an ATM environment.

There are major differences between LAN technology and ATM [8]. In a LAN data packets are broadcast to every station and the LAN protocols such as Ethernet are designed to take advantage of this shared media characteristic. In a point to point ATM network, data packets must in effect be duplicated and sent down multiple wires. Additionally, Ethernet is connectionless whereas ATM is connection oriented (either Ònailed-upÓ by PVCs or established via SVC call-set up). The LANE protocol provides an ATM network with the ability to behave like a shared-media, connectionless LAN by creating an emulated LAN. It defines a service interface for higher-layer network protocols including IP. This requires a new ATM MAC layer beneath the logical link control (LLC) sub-layer [4] to give the appearance of a shared medium such as an IEEE802.x LAN. This is implemented in a software driver that provides a common interface to upper layer LAN software as existing LAN drivers do. Many CPE vendors are implementing the protocol in adapter cards, routers and small switches.

The LANE software architecture uses a client server model. There are four components to the LANE system : (a) The LAN emulation client (LEC) whose main function is to communicate with the remote LAN emulation components (LES, BUS and LECS). (b) The LAN emulation server (LES) which provides a facility for registration and resolving a MAC address into an ATM address. (c) The broadcast and unknown server (BUS) which forwards broadcast/multicast frames and delivers unicast frames for an unregistered or address unresolvable LAN host. (d) The LAN emulation configuration server (LECS) which locates the LES and obtains configuration information for each ATM segment.. Collectively the three servers are called the LAN emulation service.

LANE only provides Layer 2 bridging, therefore the service must be provided to the telco network as Ethernet frames via a LAN Emulation Client (LEC), though in practice this could run on a direct-attached ATM server. If the service is not native to Ethernet, then a routing function must exist prior to the Service provider LEC interface.

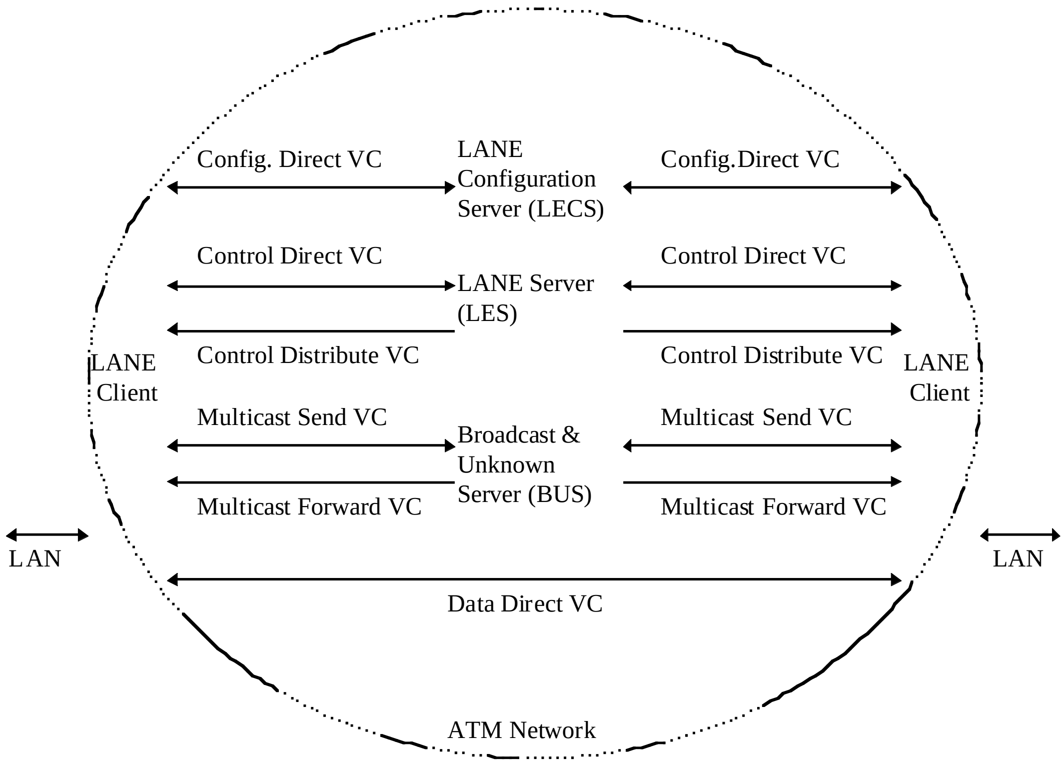

Figure 17 : Overview of LANE

Ethernet uses a 6 byte media access control (MAC) address to uniquely identify each end station (e.g. PC). ATM end-stations are identified by a 20 byte ATM address. So, to send an Ethernet LAN packet to a particular MAC address requires the LANE protocol to provide an address resolution or mapping service to identify the ATM address associated with the destination MAC address. This happens by the LEC software intercepting the MAC address and signalling to the LES which then provides the corresponding ATM address to the LEC. In a mature ATM network, the LEC could then use Q.2931 signalling to set up an SVC to the destination over which the data frames are subsequently sent. The database that maps corresponding MAC and ATM addresses is set up by the LES. If the LES doesnÕt have the destination address in its address table then the source LEC sends the data frame to the BUS which broadcasts to all stations on the ATM network.

When the Ethernet LAN station is turned on, its LEC software sends a request (LE-ARP) to the LES asking to join an emulated LAN by requesting the ATM address of the destination. In a multiple step process, the LAN client joins the emulated LAN and sends its ATM and MAC addresses to the LES which builds it into an address table. This process is very SVC intensive, with the LANE software setting up and tearing down connections continually. Large amounts of control information flow between each client and the servers for initialisation, registration, address resolution etc. There are scaling issues to be resolved with this option, particularly in the area of server resilience and distribution (i.e. where to locate the server functionality). Before SVCs are widely available, it would be possible to transport the information using four PVCs over the ADSL link. Three for the control information (LES, BUS & LECS) and one for the routed data. There are concerns that this PVC approach could make LANE totally unmanageable for a large scale ADSL deployment until SVCs are available. However, a more appropriate way forward in the ADSL fast internet access scenario would be to use a radically stripped down version of LANE to enable only one PVC to be needed (shared for BUS and data). LANE was developed to emulate the broadcast media used in LANs. However, in the target application of using ADSL for fast internet access the main aim is to establish a point to point IP link between the customers ADSL unit and the ISP. Note that multiple CPE may be connected to the ADSL remote unit. Full LANE software features are not required in this ADSL internet access scenario. Specifically the broadcast capabilities (via BUS) arenÕt required and the LES software could have reduced functionality. The client version of the LANE software could reside in the ADSL remote unit or a terminal adapter like interworking unit for the starting network scenario described earlier. The amount of processing power and memory required to implement this could therefore have a direct impact on ADSL complexity. As the network evolves to delivering ATM to the CPE as in the target scenario, any client software could reside on the CPE but the aim would be to use existing standard commercially available protocol stacks on the CPE as far as possible. The server functionality of LANE (which may potentially be a reduced functionality version) could reside in the ATM ADSL access multiplexor, the ISP server/access point router or an ATM switch (perhaps an edge switch/adjunct). Another issue for this option is where to locate the routing functionality that will allow communication between different emulated LANs.

An advantage of LANE over legacy LANs (particularly when ADSL access is employed) is that congestion is much less since most traffic is carried over dedicated connections per end user. The major advantage of LANE compared to IP over ATM is that it can support multiple protocols (such as IPX, Appletalk, DECNet etc.) and not just IP. This is because it is a layer 2 service bridging LAN and ATM addresses at the MAC layer. It is independent of any higher layer services, protocols and applications and effectively hides ATM from them. The vast majority of networks today are mixed protocol environments and so an IP only solution such as IP over ATM poses limitations. Hence recent work on MPOA described below.

The disadvantages of LANE are scalability (particularly of the BUS), router bottlenecks and cost, the need to provide an Ethernet-based service or routing at service provider, high amounts of broadcast traffic, lack of ATM QOS due to use of unspecified bit rate and that it is limited to the Ethernet maximum frame size of 1500 Bytes.

The following is a simplified view of the functions required at the ATU-R, in the Network, and at the Service Provider [11].

In the ATU-R:

- Ethernet PHY
- Ethernet MAC
- LAN Emulation Client - provides MAC level bridging
- ATM network interface (includes UNI signalling)

In the Network:

- LAN Emulation Server (LES) - provides address translation between MAC and ATM addresses.
- LAN Emulation Configuration Server (LECS) - provides LEC with addresses of the other servers.
- Broadcast and Unknown Server (BUS) - Emulates LAN broadcast features which ATM does not normally provide. Used for essential purposes such as LAN Address resolution (e.g. for IP). This is the most likely bottleneck in LANE and its implementation will need very careful consideration for a large network.
- ATM Routers - interconnecting emulated LANs. The size of an emulated LAN is limited by its ability to support broadcasts, hence there will typically be many small emulated LANs.

At the Service Provider:

- Ethernet-based service
- LAN Emulation Client
- ATM network interface

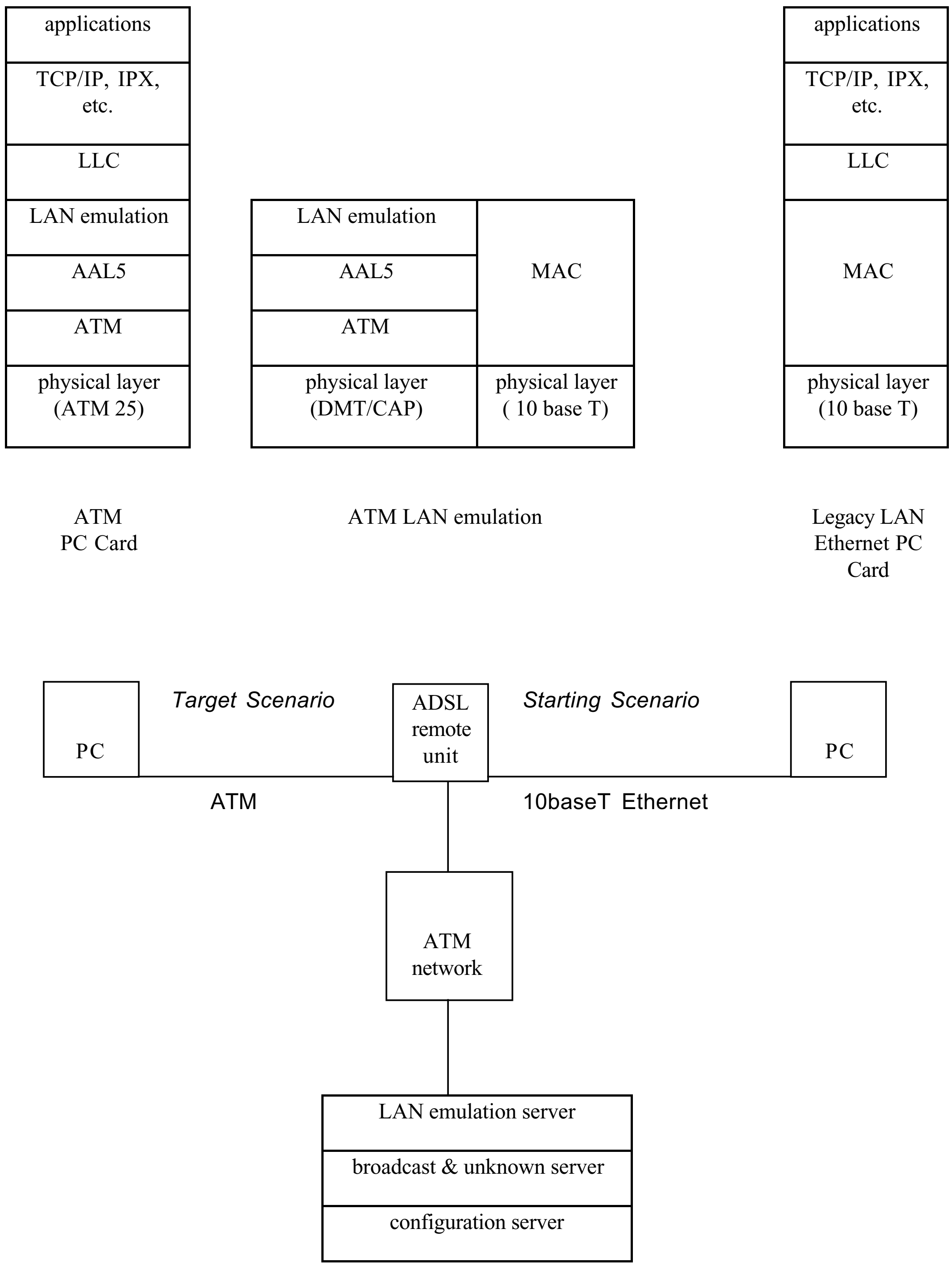

Figure 18 : LAN Emulation Protocol Stacks and Possible Location of Functionality

6.5.4.6 Option 6 : Multiprotocol Over ATM (MPOA)

MPOA, developed by the ATM forum, aims to provide network layer routing for multiple protocols, though initial work concentrates on TCP/IP. It combines and builds on the features of LANE and IP over ATM, providing a way to route IP, and in principle other protocols, with high performance and low latency. It allows traffic to be transported to its destination via a single-hop virtual circuit. It also provides access to ATM quality of service features and supports network-layer virtual subnets and virtual routing. MPOA is a recent development that is still evolving within the ATM Forum and hence is not yet widely supported by any commercial equipment. MPOA will provide end to end layer 3 connectivity across the ATM network, including hosts attached directly to the ATM layer and others to legacy LAN technologies. It will enable higher layer protocols to take advantage of ATM quality of service features and initially used the LANE specification as a baseline text. The Resource Reservation Protocol known as RSVP being developed in the IETF would be used for QoS guarantees for connections between systems over an ATM network. However, this is not MPOA specific. MPOA may use a variant of Next Hop Resolution Protocol (NHRP) of option 4 for route determination. This would use SVCs for data connections with holdtimes more like a stream of related data information as opposed to intermittent bursts. SVCs would also be used when the data service needs a QoS guarantee from the ATM network.

MPOA essentially defines a distributed router. MPOA Clients within edge devices at the periphery of the ATM network (e.g. the ATU-R) are responsible for forwarding packets while the expensive processing and intelligence of the router resides on servers within the network which build and maintain routing tables and supply routes to the edge devices on request. Traffic does not pass through the route servers, but is routed directly between edge devices over the ATM network. MPOA clients first attempt address resolution via LANE services and if this fails, they then use the MPOA service.

MPOA will use IPv6 addresses to route IP datagrams. However, IP can be carried without MPOA as discussed in the previous section. In a sense MPOA is in competition with IP over ATM in that it offers similar routing functionality although it potentially supports other protocols. It is not clear whether MPOA will be widely adopted because it may turn out that there is little use of protocols other than IP. As the LANE specification pre-dates the MPOA draft document it is viewed that LANE devices will be the first that are stable enough to offer a service. However, ultimately MPOA may provide a more easily scaled solution.

The following is an overview of the functions required at the ATU-R, in the Network, and at the Service Provider [11].

In the ATU-R:

- Ethernet PHY
- Ethernet MAC
- LAN Emulation Client - provides MAC level bridging for the local subnet
- MPOA Client
- ATM network interface (includes UNI signalling)

In the Network:

- LANE Servers: LECS, LES, BUS
- MPOA Servers: Configuration, Route, Multicast/MARS & Forwarding servers

At the Service Provider:

- Service based on IP or other protocol
- ATM host with MPOA Client(s)
- ATM network interface

6.5.4.7 Option 7 : ATM Gateway

Either the ATU-R or other CPE (e.g. a Set Top Box) could act as a gateway to the ATM-delivered network services. In this scenario, the gateway would have functionality necessary to request and control network services, and would provide some form of high level interface to the user on the Ethernet side, effectively acting as a server providing network services to the end user. Such a system could be implemented in a number of ways, but in general has the disadvantage of putting most of the complexity into the gateway, which is undesirable if this is the ATU-R. Hybrid approaches may also be possible where the functionality is shared between the ATU-R and end station, but these are likely to be messy due to both parties having to be aware of what the other is doing.

6.5.4.8 Option 8 : Cells in Frames

Cells in Frames (CIF), specified by the Cells in Frames Alliance, is designed to extend ATM protocols directly to legacy (typically Ethernet) end stations, without requiring any hardware changes at the end station [11] In effect it uses Ethernet as an ATM bearer. It achieves this by inserting a software ÔshimÕ immediately above the Ethernet card driver to package/unpackage cells into frames and manage multiple queues. The end station operates with ATM signalling and ATM ABR flow control. If ABR flow control is not available end-to-end on a particular path, then TCP can be used as a fall-back (to allow this switching, modified TCP software is needed on the end station). The end station also needs an ATM protocol stack, including UNI signalling, and this is used directly by ATM-aware applications. If required, non-ATM legacy applications can be supported using LANE, MPOA or IP over ATM, but this requires the appropriate client on the end station and the corresponding services within the network.

In this scenario, the ATU-R becomes a CIF attachment device (CIF-AD) which packages/unpackages cells to/from Ethernet frames and operates the CIF protocols. This makes it transparent to ATM, hence it does not need extra functionality for LANE, MPOA or IP over ATM: bridging or routing in the ATU-R is avoided and the required client functions for these services can be carried out by the end stations as necessary.

To make best use of the legacy protocol, up to 31 ATM cell payloads are packed into a frame, with a CIF header which includes the ATM cell header for the group of cells (there is also an option to carry cells from multiple VCs within a frame). Multiple queues are used with different priority based on the required QOS.

The CIF-AD would normally have ATM switching capability, but could be a multiplexer or physical layer converter, and this may be an attractive option since it may then be possible to avoid having ATM signalling in the ATU-R.

The CIF attachment device (e.g. the ATU-R) will appear to the user as a switched Ethernet hub, i.e. if multiple ports are provided, each should be a separate collision domain, ideally dedicated to one end station, largely avoiding collisions. It is optional for a CIF-AD to support multiple CIF end systems on a segment but this is undesirable because it allows Ethernet collisions making it impossible to guarantee QOS. The CIF-AD may or may not support mixing with non-CIF (legacy) LAN traffic. Users may need this if a LAN is already used, but sharing results in collisions which compromise ATM QOS. Also, the CIF-AD must then provide bridging or switching between ports for the legacy traffic. In such cases, use of switched Ethernet may be essential.

The expected configuration is a single CIF end system sharing a half duplex LAN segment with a single CIF-AD port. This allows proper ATM QOS agreements to be made for ABR service (subject to preventing the capture effect discussed below).

Sharing a segment with multiple CIF end stations or legacy LAN stations means that there can be no QOS guarantees so this is discouraged. This can still provide a valid ATM service however (i.e. unspecified bit rate, UBR, or ABR with Minimum Cell Rate = 0).

For ABR, the CIF-AD should act as a virtual source/destination for the Resource Management (RM) cells, reducing their rate to approximately 3% of the packet rate (from 3% of cell rate on the ATM side). This is to allow software ABR flow control to operate on end stations at an acceptable processing load and interrupt rate.

The CIF-AD also needs a mechanism to avoid the Ôcapture effectÕ which can occur when Ethernet utilisation rises above 50-60%. This occurs if one station transmits a number of frames in rapid succession, without allowing the other station to gain control of the medium.

The following is an overview of the functions required at various locations in this scenario [11].

In the end station:

- ATM protocol stack
- ATM UNI signalling
- CIF shim for cell packaging, queue management and ATM flow control
- Modified TCP for fall-back flow control
- Existing driver
- Existing Ethernet MAC and PHY

In the ATU-R (CIF-AD):

- Ethernet PHY(s)
- Ethernet MAC(s) (for each port)
- CIF protocol with multiple queues to ensure QOS
- Virtual source/destination reduces RM cell rate & hence processing load on end station
- ATM network interface (includes signalling if ATU-R is a switch - possibly this can be avoided)

In the Network:

- If services are pure ATM, nothing special is required
- If services are not pure ATM, may require LANE, MPOA or IP over ATM capability

At the Service Provider:

- Pure ATM-based service, or
- Service based on LANE, MPOA or IP

6.5.4.9 Option 9 : Alternative Remote Bridging Methods

There are alternative methods for enabling the customers PC to communicate with say an internet service provider (ISP) over an ATM network incorporating ADSL access. An appropriate protocol stack built into the ADSL remote unit and a corresponding stack at the ISP entry point can enable Ethernet MAC layer frames to be remotely bridged over an ATM PVC between the customerÕs ADSL unit and the ISP. Remote Bridging is a simpler alternative to LANE. This does not try to emulate a fully functional LAN but instead provides point-to-point transport of LAN frames over the ADSL link and through the ATM network. In this scenario, the ATU-R contains a half-bridge, which encapsulates Ethernet frames and communicates over an ATM channel with a corresponding half-bridge within the network or at the service provider (for example an ISP) at which point the encapsulation process is reversed. Possible encapsulation protocols that can be used between the AAL5 layer and Ethernet MAC layer in the ADSL remote unit are IEEE 802.2 Logical Link control with Sub-Network Attachment Point header (LLC/SNAP) and Point-to-Point Protocol (PPP). Remote Bridging is simpler than LANE, but it shares the disadvantages associated with operation at layer 2. Broadcast traffic which passes through the bridges will be concentrated at the service provider, hence there is a scalability issue in determining how much traffic concentration should be used. Packet filtering by the ATU-R may be appropriate to ensure that only essential traffic is forwarded and also to provide protection against accidental or deliberate flooding of the remote bridge.

6.5.5 Summary

The table below summarises the key functions required in the interface between the home and the access network for each of the migration approaches considered [11]. The obvious place to carry out these functions is in the ATU-R, but it may be more economic to locate some or all of them further back in the access network e.g. in a street multiplexer or at the local exchange. For comparison, the pure ATM case is included in which the ATU-R only needs to provide physical layer translation between different home and access network ATM physical layers, plus limited VC-based routing to differentiate intra-home and external traffic. There remain several issues to resolve for ATM over ADSL and some of these are described in [12].

Pure ATM	Remote Bridging	LANE	IP	MPOA	Gateway	CIF-AD	CIF ÔMUXÕ
VC routing ATM Layer Home ATM PHY	Filtering Encapsulation 802.3 MAC 802.3 PHY	ATM UNI LANE Client 802.3 MAC 802.3 PHY	ATM UNI LIS Client IP Routing IP ARP 802.3 MAC 802.3 PHY	ATM UNI MPOA Client LANE Client 802.3 MAC 802.3 PHY	ATM UNI Service control User interface Routing 802.3 MAC 802.3 PHY	ATM UNI RM handling CIF queuing CIF packing 802.3 MAC 802.3 PHY	RM handling CIF queuing CIF packing 802.3 MAC 802.3 PHY

Table 2 : Functionality required at the home/access network interface

An low-level ATM interface to the access network is assumed in all cases.
Where ATM UNI is shown, this implies that a full ATM UNI including signalling is required.

All of the solutions considered involve increased complexity and reduced performance compared with a pure ATM solution (the target network scenario)). If Ethernet congestion occurs it is hard to see how QOS can be guaranteed. Congestion may be controlled using switched Ethernet, but this is a higher cost option which would not normally be installed in the home.

6.5.6 References

1. ÒInteractive Video on DemandÓ Daniel Deloddere, Willem Verbiest, Henri Verhille (Alcatel Bell). IEEE Comms, May 1994 Vol. 32 No. 5
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5. ATM Forum, LAN Emulation SWG Drafting Group, ÒLAN Emulation Over ATM Specification version 1.0Ó January 1995.
6. ÒLAN Emulation Bridges LEGACY LAN and ATM NetworksÓ Time to Market, HP, Issue 2, Summer 1996.
7. ÒATM LAN EmulationÓ Finn N & Mason T., IEEE Communication Magazine, June 1996, pp 96-100.
8. ÒLAN Emulation on an ATM NetworkÓ Truong H.L., Ellington W.W., Le Boudec J.Y., Meier A.X. & Pace J.W., IEEE Communications Magazine, May 1995.

9. ÒInterworking with TCP/IPÓ VOL. 1., Cromer D.E., Prentice Hall, 1995.

10. ÒADSL in an ATM Network : From Internet only to Full ServiceÓ ADSLForum96-082, Gavin Young, BT, September 19th 1996 (London Meeting).

11. ÒATM/Ethernet Interworking for Home NetworksÓ ADSLForum97-010, Robert Dearnaley, BT, March 19th 1997 (Amsterdam Meeting)

12. ÒComments on Unresolved ATM over ADSL IssuesÓ ADSLForum97-142, Alan Weissberger, NEC, September 16th 1997 (Brussels meeting)

6.6 INTERNET ONLY VIA ÒIPÓ ADSL TO ÒFULL SERVICEÓ SET VIA ATM ADSL

6.6.1 Starting Network Scenario

A customer is provide with IP based services over ADSL from a router plus Ethernet switch data-centric architecture.

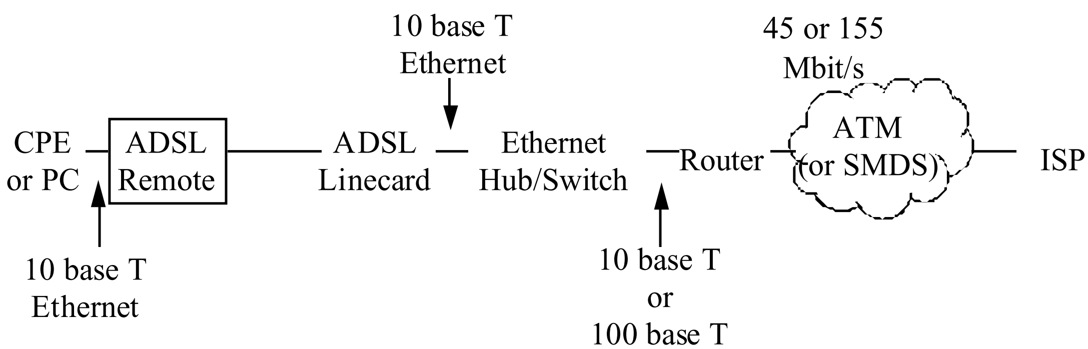


Figure 19 : Internet Access via ÒIPÓ-Based ADSL Architecture

6.6.2 Target Network Scenario

The customer is provided with a wide variety of services (e.g. VoD and LAN access) that may necessitate the use of multiple protocols via a DSLAM type of network architecture that transports ATM over the ADSL link to the customers CPE.

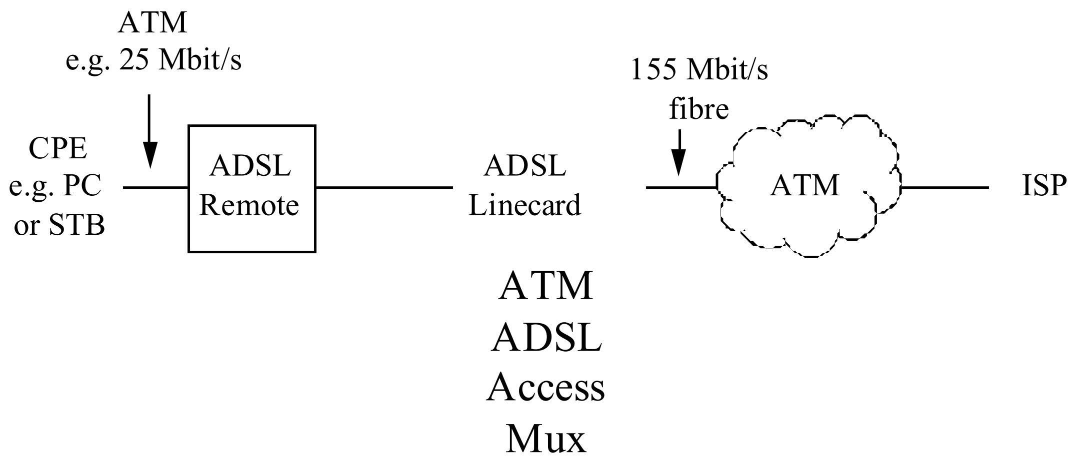


Figure 20 : Multi-Service Delivery via ATM-Based ADSL architecture

6.6.3 Drivers

Desire to sell a new service such as VoD over the same copper pair that was previously only used to deliver data-centric services such as remote LAN access and fast internet access.

The desire to have a future proofed access network capable of transporting many new services with different QoS requirements simultaneously over the same ADSL line.

6.6.4 Options

The obvious but undesirable option is to ÒforkliftÓ the initial ADSL access network and replace it with ADSL equipment that transports ATM to the customers premises. If the router provides an ATM interface then it may be possible to employ a network configuration that doesnÕt require removal of this ÒsubsystemÓ. An alternative is to use a form of access multiplexor that contains layer 2 and layer 3 internetworking functionality. This could enable it to connect either to an Ethernet Switch/router or ATM network depending on the core network interface card. The internetworking capability could enable it to initially terminate ATM in the access mux and forward Ethernet frames carrying IP packets to the customer. Later it could be ÒreconfiguredÓ to convey ATM cells all the way to the customers premises (see section 6.5). The remote unit would probably then require upgrading.

It should be noted that in some countries the use of either layer 3 protocol conversion or routing functionality (if deemed analogous to switching) can have a regulatory implication on the classification of the offered service (e.g. perhaps as some form of enhanced service). This may have an impact on the ability of a telco to undertake certain network migration steps described in this working text such as the scenario described in this section..

6.7 INTERNET ONLY VIA ÒIPÓ ADSL TO ÒFULL SERVICEÓ SET VIA ÒIP-ONLYÓ ADSL

6.7.1 Starting Network Scenario

A customer is provide with IP based services over ADSL from a router plus Ethernet switch data-centric architecture. The general structure of the IP-over-ADSL access networks is an extension of the traditional enterprise branch access routing model. All subscribers of any given service provider are assigned IP addresses out of that subscriberÕs domain, either statically or dynamically. Either IP static routing or boundary routing is used between the subscriber premise modems and the ISP POP router. This basic network structure enables IP access from the subscriber premise to the Internet-at-large.

6.7.2 Target Network Scenario

A customer is provide with a wide variety of services (e.g. VoD and fast internet access) which are IP based over ADSL from a router plus Ethernet switch data-centric architecture.

6.7.3 Drivers

Without a doubt, Internet access is one of the driving applications behind early deployment plans for ADSL. Given the frame-based nature of this ÒKiller AppÓ itÕs no surprise that many service providers have based the design of early ADSL networks on the IP-over-ADSL paradigm. While the sheer speed of this basic Internet access over ADSL may be enough of a service differentiator for some ISPs, long term competitive issues as well as requirements for value-added revenue on the part of many ISPs will likely drive the need for more exotic applications. There may be a desire to sell a new service such as VoD over the same copper pair that was previously only used to deliver data-centric services such as IP based remote LAN access and fast internet access. There may also be a desire to upgrade the service capability of the router and Ethernet switch based network with minimal change out of network equipment. Two very attractive value-added services that may be desirable enhancements are Virtual Private Networking (VPN) and Reserved Bandwidth Services (RBS).

6.7.4 Options

6.7.4.1 Overlaying VPNs on Top of IP over ADSL

VPNs require the establishment of a peer relationship between the subscriber PC and a foreign network domain over the public Internet. The foreign domain is most commonly a central corporate network that the subscriber wishes to connect with. VPN service enables the subscriber to access corporate resources behind the corporate firewall utilising an IP address outside the domain of the subscriberÕs ISP. VPNs also enable the subscriber to utilise protocols other than IP such as Novell IPX when accessing corporate resources.

The ability to connect a subscriberÕs PC communication stack with a foreign domain over the ISPÕs network is most easily accomplished using the Layer 2 Tunnelling Protocol (L2TP). Currently defined as an Internet Draft in the Internet Engineering Task Forces (IETF) PPP working group, L2TP is designed to allow secure access from a workstationÕs protocol stack to a distant networking domain over an intermediate networking domain such as the Internet.

L2TP-enabled subscriber PCÕs can utilise an ISPs Internet access service to connect to their corporate central siteÕs L2TP access concentrator (LAC). The L2TP protocol uses an ISP-supplied IP address to ÒTunnelÓa PPP session through the Internet where it is terminated in the LAC. The LAC uses the PPP tunnel to authenticate and authorise the subscriberÕs PC. Once authorised, the subscriber PC can utilise both IP and non-IP protocols across the PPP tunnel as though the PC where directly connected to the LAC via a PPP leased line.

This allows the subscriber PC to use corporate specific IP addresses as well as protocols such as IPX over an ISPs existing backbone without the ISP having to upgrade to multi-protocol routing or change the IP routing tables in itÕs router network.

6.7.4.2 Reserved Bandwidth Services

The IETFÕs Resource Reservation Protocol (RSVP) enables subscriber PCÕs to reserve end-to-end network bandwidth. Functionally, the RSVP protocol is used by a subscriberÕs PC-based application, presumably through API hooks, to request a specific quality of service for a specific IP stream through all routers between the subscribers PC and the destination node.

This ability to reserve and enforce QoS renders feasible reserved bandwidth applications such as video conferencing and high quality Internet telephony.

6.7.4.3 Applications Considerations

Both VPNs via L2TP as well as Reserved Bandwidth Services via RSVP pre-suppose extensions to the subscriberÕs operating environment that are not yet widely available. As an example L2TP is currently available for Windows NT 4.0 platforms but not Windows 95 platforms. Further, service gateways that implement the LAC functionality are not widely available.

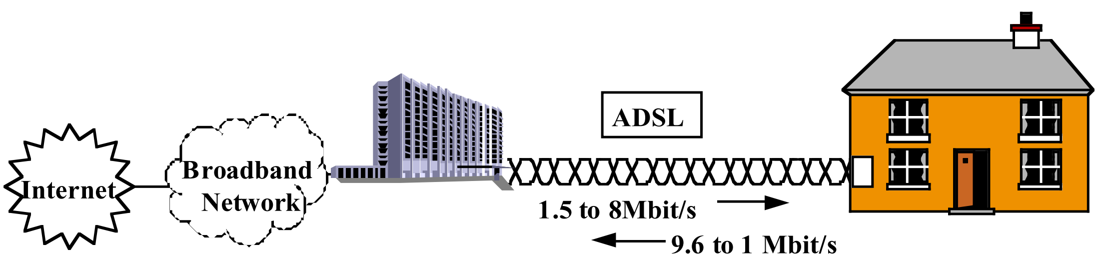
Even more significantly, RSVP, by itÕs very nature, requires end-to-end deployment in order for bandwidth contracts to be well guaranteed. Given the extremely early stages of RSVP deployment, it may be some time before itÕs useful across the Internet. Also required in order for practical RSVP deployment are well implemented APIs as well as billing/authorisation mechanisms that ensure the protection of the ISP business case vis- -vis bandwidth reservation.

The initial Internet-focused IP-over-ADSL deployment can be migrated to more of a full service network given the adoption of some leading edge IP-based technologies. As examples, both VPN and Reserved Bandwidth Services are feasible in this migrated network but are greatly dependent on the pace of implementation in the subscriber PC operating systems environment.

6.8 ADSL SERVICE DELIVERY TO VDSL SERVICE DELIVERY

6.8.1 Starting Network Scenario

A customer is provided with a high-speed ADSL link. The services that could be delivered over the ADSL link range from internet access to VoD. However, in the short term it is thought by many that the most likely single service that may be a viable business on its own is internet access. Therefore, the starting network scenario is internet access using ATM or TCP/IP over an ADSL transmission system.



Figu re 21 : Internet Access via ADSL

6.8.2 Target Network Scenario

The customer is provided with a high-speed VDSL link. It is generally agreed that for xDSL to ultimately be competitive, it must provide a mixture of telephony, video and data services. This so-called Full Service Network (FSN) will require higher bit-rates and more flexible operation than that which is required for a single service, such as internet access. Therefore, the target network scenario is a FSN using ATM over a VDSL transmission system.

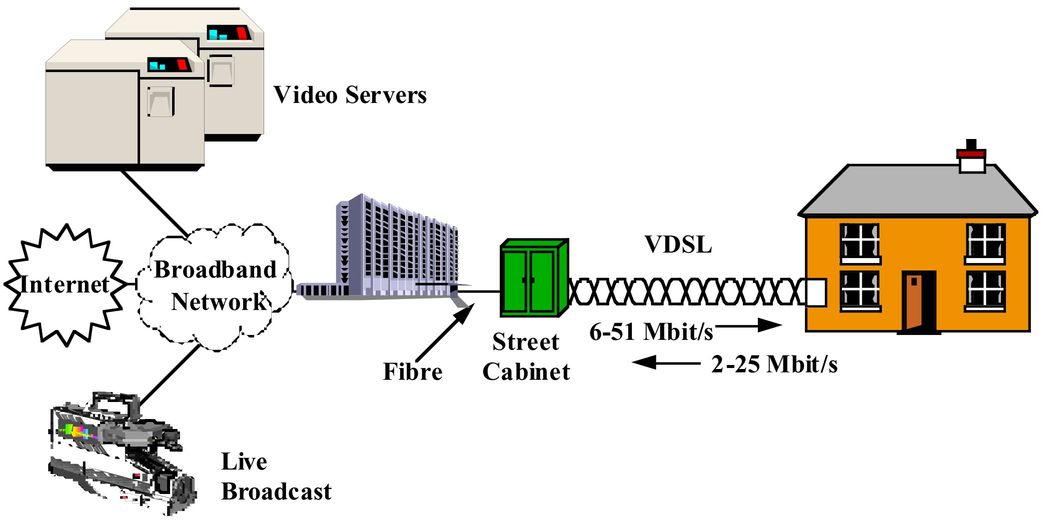


Figure 22 : VDSL-Based Full-Service Network

6.8.3 Drivers

ADSL can support a variety of services, ranging from VoD to internet access. Initial trials of ADSL focused on delivering services aimed at the mass residential market, such as VoD, home shopping and home banking. However, recently there has been a flurry of activity espousing the virtues of supporting high-speed internet access using ADSL. It seems likely that the Telcos will initially employ ADSL to provide high-speed internet access over the existing copper wires of the distribution area. Data will be transferred using ATM or TCP/IP from an access multiplexer, primarily located in the CO, to a single CPE within the home. This is an adequate network architecture for supporting a single service, but will not suffice when a FSN is required.

In the near future consumers will desire sophisticated and bandwidth-intensive services that will far outstrip the capacity of ADSL transmission systems. An FSN can provide multiple telephone channels, HDTV, VoD and high-speed data services to the subscriber. One method that can be employed to carry this mixture of services is to use ATM over VDSL, from an access multiplexer to multiple CPEs within the home. Once again the existing copper wires of the distribution area are re-used, but in this instance the multiplexer will be sited at a flexibility point in the network, such as at a Feeder to Distribution Interface (FDI) or Serving Area Crossconnect (SAC). Alternatively, the multiplexer could be located in the basement of a multiple-dwelling unit or high-rise apartment block, where the broadband signal is transmitted over the existing copper wire riser cables. In either eventuality ADSL systems will probably already be employed in the Telco's region and thus a clear migration path is required to facilitate a smooth transition to VDSL. The next section details some of the options available in evolving towards that goal.

6.8.4 Options

Three major elements impact the migration path from an ADSL service to a VDSL service. These are the type of signalling used over the xDSL link, the location of the access multiplexer and the interfaces defined for the access multiplexer.

6.8.4.1 ATM ADSL to ATM VDSL

Internet access can be provided using ATM over ADSL, where the TCP/IP data is packetized into an ATM cell. When the xDSL transmission system is upgraded to VDSL a smooth transition can be facilitated. The access multiplexer and CPEs will have the same ATM interface to the xDSL modems. Additionally, if the interface chips and multiplexer backplane are flexible enough to support higher speed transmission, then it would only be necessary to change the xDSL modems when migrating from ADSL to VDSL. This is illustrated in the following figure.

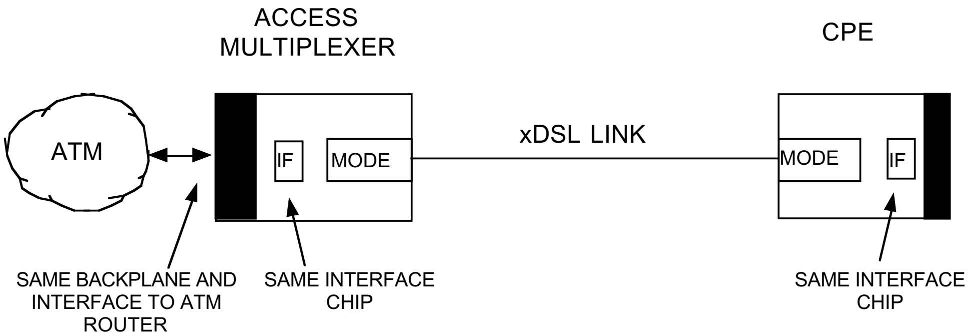


Figure 23 : ATM Delivered to the Customer Using ADSL or VDSL

Other issues to consider that will influence the ease of this migration are (a) the fact that many DSLAM ATM ADSL multiplexors are being developed with 155 Mbit/s interfaces where as a VDSL ONU will probably require at least a 622 Mbit/s fibre feed. (b) the work on fast/slow paths through ADSL and VDSL transceivers will have an impact since standardised ADSL has both paths but some VDSL implementations may end up only having one latency path.

6.8.4.2 TCP/IP ADSL to ATM VDSL

If high-speed internet access is provided using TCP/IP over ADSL, then the access equipment will now contain a service specific element, thus reducing its flexibility. Moreover, migrating a TCP/IP data-centric platform to one which supports a FSN via ATM would not be a simple process. The backplane, its interfaces and functionality, together with the CPE, would all have to be changed to support ATM over VDSL. Indeed, the complete access equipment would probably have to be changed out right from the router interface at the CO to the CPE, as illustrated in the following figure.

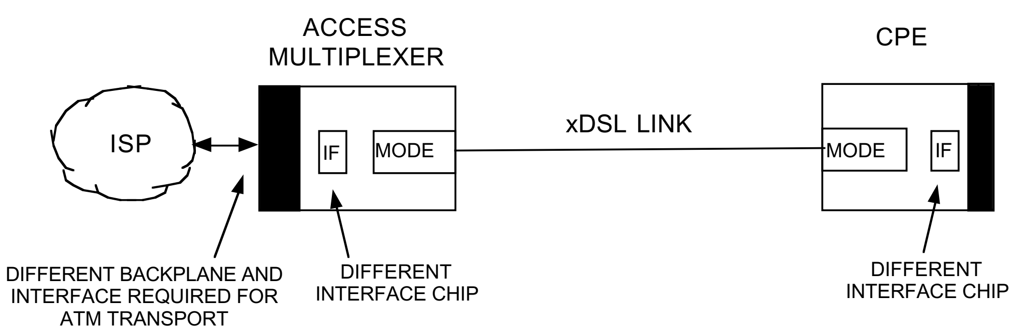


Figure 24 : Only TCP/IP Delivered to the Customer via ADSL

6.8.4.3 Location of the Access Multiplexer : Central Office

ADSL is currently defined to transport 6 Mb/s up to 9 kft from the access multiplexer. Initially, access multiplexers which support ADSL will reside in the CO. VDSL, on the other hand, is currently defined to transport up to 52 Mb/s up to 4 kft from the access multiplexer. For VDSL, the access multiplexer will now reside at a flexibility point in the network, such as at a FDI/SAC, or in the basement of a multiple-dwelling unit. Therefore, in this instance, it is not possible to migrate CO-based ADSL to VDSL.

6.8.4.4 Location of the Access Multiplexer : Remote Terminal

In some wiring topologies it will be necessary to locate the ADSL based access multiplexer in the outside plant as a Remote Terminal (RT). The RT could be located at a FDI/SAC, co-located with a DLC, or located in the basement of multi-dwelling unit. The RT may have to be hardened to withstand the physical and environmental requirements as defined in telco specifications. Additionally, it is now necessary to provide some sort of concentration functionality back at the CO to terminate multiple RTs. This architecture is illustrated in the following figure.

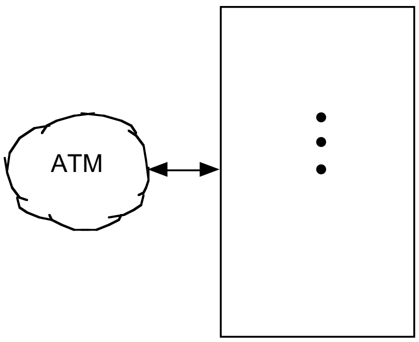


Figure 25 : ADSL and VDSL Delivered from a Remote Terminal

If the copper wire loop or riser length is short enough, then the same RT could support ADSL linecards today and VDSL linecards in the future. However, this does assume that the access multiplexerÕs backplane can support VDSL bit rates. Nonetheless, this would provide easy migration to higher rate services when VDSL transceivers become available.

6.8.4.5 Access Multiplexer Interfaces

In order to truly migrate an ADSL based system to a VDSL based one it is necessary that the access multiplexer can accept input from both narrowband and broadband sources. The backplane of an xDSL access multiplexer should be able to accommodate input from the following sources:

- Broadband data over ATM from an Internet edge switch and other data sources
- Narrowband telephony from a Class 5 Switch
- Broadcast video over ATM from content providers
- VoD over ATM from content providers

6.8.5 References

1. ÒADSL to VDSLÓ ADSLForum96-077, Lawrence Ebringer, Next Level Communications, September 19th 1996 (London Meeting).

6.9 NGDLC-Based ADSL to ONU-Based ADSL/VDSL

6.9.1 Starting Network Scenario

ADSL service(s) is (are) provided from NGDLC-based equipment; that is, the ATU-C is located at the remote site of the NGDLC (Next-Generation Digital Loop Carrier). Figure 26 shows a Digital Subscriber Line Access Multiplexer (DSLAM) that provides the wideband/broadband multiplexing function at the Remote Digital Terminal (RDT) site. The NGDLC carrier provides the narrowband services and the DSLAM provides the wideband and broadband services, including ADSL access. Both are managed by a common SNMP platform and connect to the central office via an SDH/SONET ring.

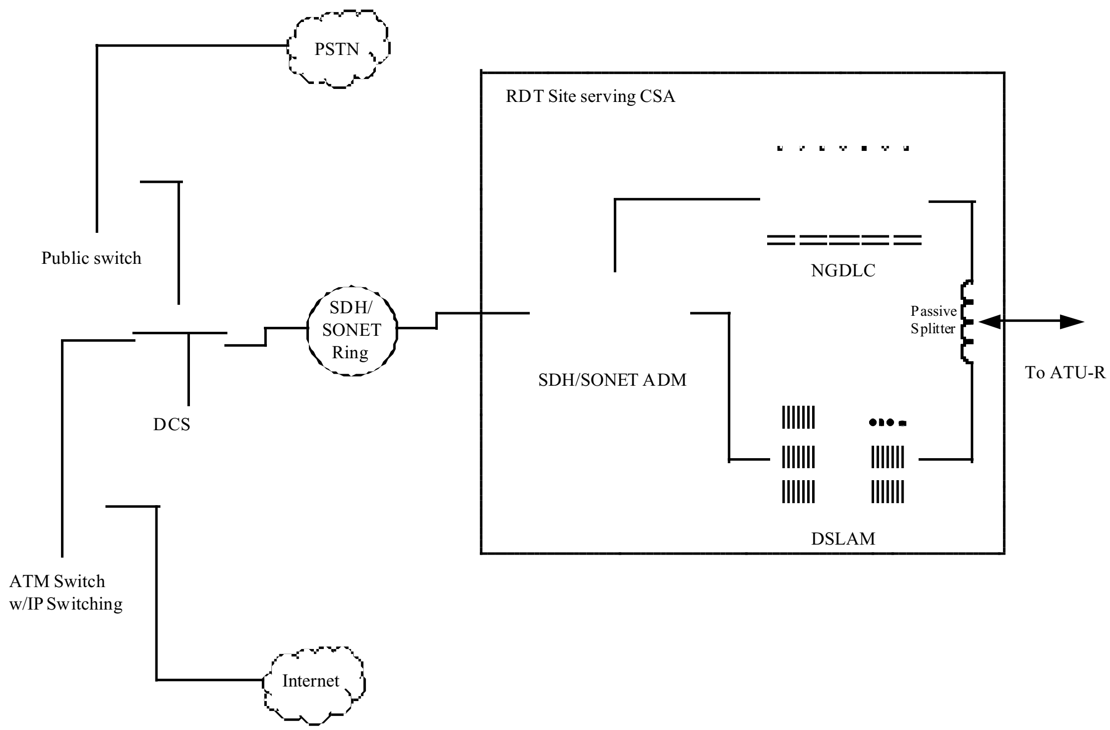


Figure 26 : NGDLC-Based ADSL

The SDH/SONET ring terminates into a Digital Cross-connect System (DCS), with the narrowband traffic connected to the Public switch and the ADSL traffic connected to an ATM switch (or router). Figure 1 shows a loose integration of the DSLAM and NGDLC products. Eventually, the DSLAM functions would be incorporated into the NGDLC product.

6.9.2 Target Network Scenario

ADSL service(s) is (are) provided from the ONU equipment; that is, the ATU-C (VDSL or ADSL) is located at the remote site of the ONU (Optical Network Unit) of a Fibre-To-The-Curb (FTTC) deployment. Figure 27 shows the migration of fibre closer to the home (or small business) by adding the Optical Network Unit (ONU), which terminates the fibre and provides broadband, wideband, and narrowband services to the home via VDSL or ADSL. In addition to an SDH/Sonet ring, the fibre feed may use point-to-point or PON topologies.

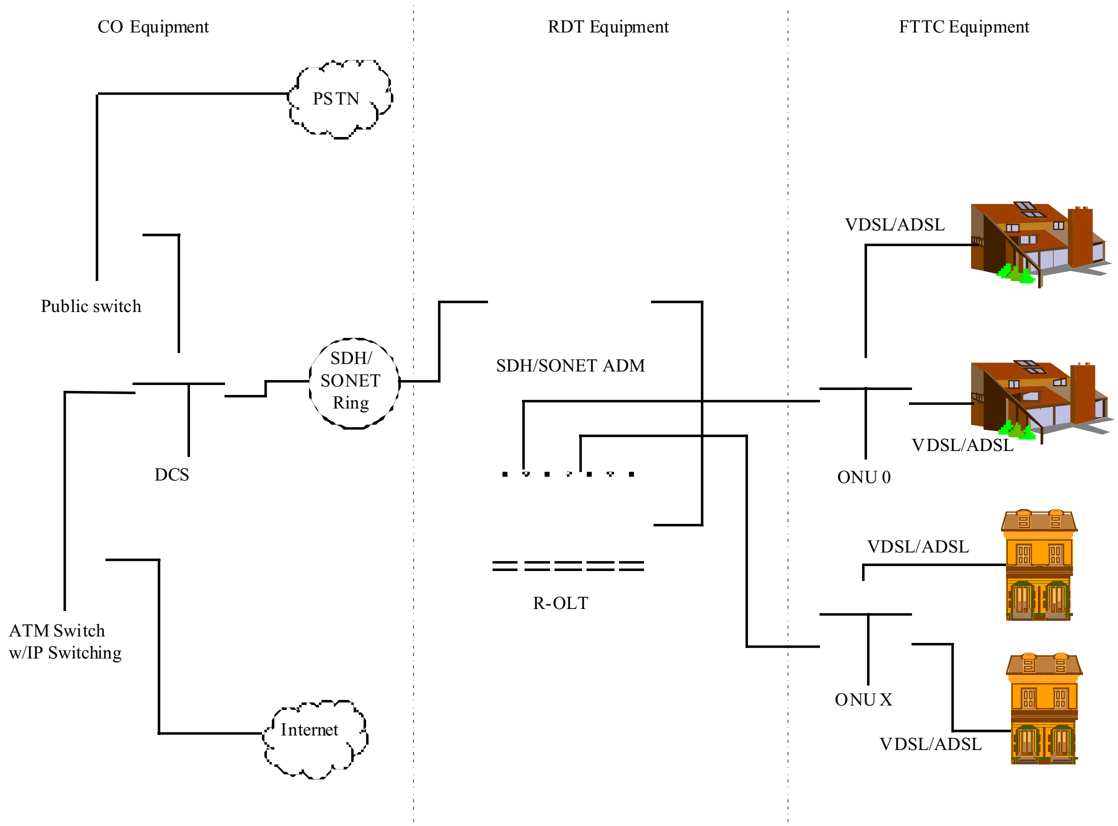


Figure 27 : ONU-Based ADSL/VDSL

Both VDSL (up to 52 Mbit/s) and ADSL (up to 13 Mbit/s) would serve homes and small businesses from small ONUs available in several sizes: from small ONUs (4-8 homes) for residential areas to large ONUs (serving an apartment building). ADSL connections at the ONU would serve wideband or broadband services to homes falling out of the limited range of VDSL (rural locations, for example).

The interface between the ONU and Remote Optical Line Termination (R-OLT) could be point-to-point optical fibre or a passive optical network with a 1:n split (n=16 to 32, for example). The R-OLT-to-ONU connection may be proprietary in nature.

6.9.3 Drivers

While high-speed Internet access is the ÒkillerÓ application for the deployment of ADSL, whether C.O.- based or carrier-serving-area based, the deployment of a Fibre To The Curb (FTTC) infrastructure with VDSL deployment must depend on new services to pay for the FTTC deployment. Like ADSL being in competition with cable modems, VDSL deployment (via FTTC) will be competing with the Hybrid-Fibre-Coax (HFC) structure.

The first driver has to do with a new market for telephone operating companies. Now that regulation and monopolies are rapidly disappearing, intense competition is beginning between cable television and the traditionally regulated telecommunication companies. FTTC deployment will bring enough bandwidth to the home so that services previously only economical via cable systems can also be provided by FTTC systems. For example, a switched digital broadcast service could compete with an analogue broadcast service from an HFC network. In other words, FTTC deployment will take place in many areas as competition to HFC deployment.

The second driver may be service quality standards. Both FTTC and HFC infrastructures can support future broadband multimedia services. Cable companies will deploy HFC networks, but telecommunications companies have the option to deploy either FTTC and HFC, depending on the economics and competition in the area.

Although cable companies have tried to improve their network quality customer service, the public generally has a very poor opinion of the service quality of cable companies. As an example, many of todayÕs cable modem trials and initial deployments are from companies with different names than their sponsoring companies. The name change is occurring so that customers donÕt think of this service as a cable television service with the history of poor quality and customer service. As cable companies begin offering telephony services, the same strategy will likely be employed. If FTTC costs can compare with HFC costs, then the telephone operating companies will have a clear advantages in the quality and customer service areas that they can exploit and give FTTC a competitive advantage. It will be interesting to see if cable operators can enough improvements in these areas to attract customers for lifeline services such as telephony.

A third driver is the array of new services that can be provided with FTTC. ADSL can provide the high-speed Internet access and limited Video ON Demand (VOD), but VDSL-capable Optical Network Units (ONUs) within 300 meters of homes and small businesses will add services such as digital broadcast with hundreds of channels and VOD with large libraries of videos to choose from. FTTC pushes fibre very close to the home or small business site, making it the final step before an eventual all-fibre network. Small ONUs (4-8 homes) will serve lower-density residential areas and larger ONUs (up to about 50 homes) for higher-density areas, apartment complexes, and small business parks.

FTTC installations will first be justified for new-build situations, but the demand for the services provided by FTTC will make it a viable alternative to HFC networks. The success to FTTC deployment (and VDSL) will depend on the cost optimising of the ONUs since most of the initial cost comes from the ONUs. Besides VDSL, ADSL can also be deployed from the ONUs for low-density and rural applications when the VDSL distance limit is exceeded.

A fourth driver will be in the area Remote LAN Extensions (RLEs) for high-performance telecommuting and ATM. Moving the ONU close to the home or small business will allow other symmetrical interfaces (e.g., ATM Forum, IBM, etc.) to provides services were the asymmetrical aspect of ADSL and VDSL are inappropriate.

While is there has been no ÒkillerÓ application for FTTC deployment discovered, as yet, the variety of services possible will make FTTC economical to deploy. In fact, that point of FTTC is that it is a service-independent network, which can carry all types of services, whether asymmetrical or symmetrical in nature.

A fifth driver will be the added security provided by a switched architecture as opposed to the broadcast nature of HFC networks. A data or video stream never leaves the Host Digital Terminal (HDT) if the home is not authorised to see it. Also, the star topology of FTTC ensures that programs or data going to one home is not available to another home.

6.9.4 Options

One option to FTTC is to deliver only digital services (requiring set-top boxes and/or PC cards), or, using a relatively new option provided by vendors, also provide an analogue video signal eliminating the need for set-top boxes when only broadcast video services are needed. This option feeds the analogue signal to the ONU via a coax cable that also powers the ONU. This analogue network is much simpler than the HFC network because it only uses a 450-MHz spectrum and it only has to a one-way system since the digital portion of the FTTC provides the two-way infrastructure.

Another option that telephone operating companies have is to deploy an HFC network that can evolve to a FTTC network once the demand for interactive and switched services expands. An operating company can initially provide only narrowband telephony services via the HFC network (with its quality and customer service reputation advantage over cable operatorÕs telephony service), then add the broadcast video services and digital services as the market develops.

6.9.5 References

1. ÒNGDLC-Based ADSL to ONU-Based ADSL/VDSL (FTTC)Ó ADSLForum96-081, Tom Miller, Siemens, September 19th 1996 (London Meeting).

6.10 VDSL FOR RESIDENTIAL SERVICES TO VDSL FOR BUSINESS SERVICES

6.10.1 Starting Network Scenario

The telco has begun its initial deployment of VDSL to serve the residential market.

6.10.2 Target Network Scenario

The telco now wishes to use the same basic hybrid fibre/copper architecture to serve business customers.

6.10.3 Drivers

The drivers that may cause a telco to consider moving from use of VDSL for residential customers to also using it for business customers include : It may be quicker and cheaper to deploy a hybrid fibre/copper access connection with VDSL rather than deploy fibre all the way to the business. In some areas, business and residential buildings may be mixed or even co-located making a homogenous access solution desirable from an operations perspective. The VDSL link may be needed to satisfy the businesses growing thirst for bandwidth driven by applications such as CAD/CAM or other increasing needs to access centralised company databases. Also, the VDSL connection may be used to replace multiple ADSL or T1 connections.

6.10.4 Options/Issues

The relative density of business customers in some locations will have an impact on the economic viability of this evolution strategy due to the need to share the costs of the fibre and ONU electronics across a sufficiently large customer base. The characteristics of the business communications to be carried over the VDSL access system will be different to the residential customers in a number of ways. The business VDSL connection may require new and different customer interfaces than the residential connection (e.g. G.703, T1 etc.). A business may well use more CPE due to having several personnel acting as Òpoints of consumptionÓ for information from a broadband wide area network. This could require greater channelisation of the VDSL link. The addressing and numbering issues associated with multiple channels will be greater than for residential users. There may well be a different tariffing regime for the business customers (e.g. per cell/packet or Mbyte as opposed to say flat rate). This could impact the system management and operations architecture.

The business customer may require more upstream bandwidth for example if it is hosting a Web site. Also, the business customer may require more than one POTS line. The residential VDSL connection may be quite asymmetric but the business VDSL connection with a greater requirement for upstream bandwidth may be symmetric. Mixing of these two types of VDSL in the same area and hence cables will raise crosstalk compatibility issues between the residential (asymmetric) and business (symmetric) VDSL systems. The spectral compatibility with ADSL also needs to be considered. These issues will impact the performance of the various systems in the cable and so planning/deployment rules must be devised with care.. Symmetric VDSL systems wonÕt have as much range as asymmetric systems.

A business connection is likely to have more exacting performance requirements than a residential connection. Aspects to consider are quality of service (QoS), security, availability and resilience. The degree of acceptable ÒoverbookingÓ on the fibre feeder connection is likely to be less for business customers. To meet some business targets, multiple copper drop VDSL feeds may be needed together with fault tolerant/redundant ONU electronics and diverse routing of the ONU fibre feeds. VDSL has the potential (although extremely difficult) for data wire taps compared to FTTH. Hence some business applications running over this infrastructure may require the use of encryption for peace of mind of the customer. The vulnerability of the street electronics in the ONU to vandalism may also be a concern to some customers. Many cable companies have suffered from the theft of back-up batteries from street cabinets. Modern ONU enclosure technology with alarms will help mitigate this problem.

6.11 ADSL FOR BUSINESS SERVICES TO ADSL FOR RESIDENTIAL SERVICES

6.11.1 Starting Network Scenario

The telco has initially deployed ADSL to deliver business services such as remote LAN access and high-speed internet/intranet access. The initial customer base are large corporate early adopters wishing to provide connectivity to teleworkers and branch offices. The services are also sold to small and medium enterprises and SOHO business customers.

6.11.2 Target Network Scenario

The telco now wishes to use the same basic network architecture with itÕs ADSL access network to deliver mass market services to residential customers.

6.11.3 Drivers

The drivers for this network migration step include : The desire to start off by targeting early adopters of technology who will pay more for a premium service i.e. to target the top end of the market initially. This is then followed by the desire to drive up volume and customer penetration to increase market share/profit but also to help reduce per unit costs enabling the service offering to be priced so that it is attractive to a wider customer base. The advent of more user friendly applications may also make the targeting of residential customers viable when previously only business customers with communications specialists could fully exploit the technology. The trend towards telecommuting may also help drive this migration step. If a customer has remote LAN access via ADSL from home for business purposes, packaging in a VoD service over the same line may be an incremental revenue source for the telco without significant additional infrastructure costs in the access network.

6.11.4 Options/Issues

An obvious issue is whether the initial systems architecture deployed for a small number of early adopter business customers (e.g. router/Ethernet architecture) is scaleable for the mass residential market and can it support residential applications such as VoD. Also, does the initial deployment for business customers fit with the telcos long term strategic vision for a residential broadband platform (which is possibly ATM based). Will the initial business customer offering be a standalone legacy network requiring its own processes and support staff or can it be evolved economically (including management systems) to the strategic mass residential solution. The initial business offering over ADSL could well be very IP/data centric e.g. LAN and Internet access only. However, a mass residential offering may require greater packaging of a wide range of services for it to be successful (e.g. including VoD, broadcast TV, games and home-shopping). This may necessitate more of a multi-service delivery platform.

There may well be a different tariffing regime for the business customers (e.g. per cell/packet or Mbyte as opposed to say flat rate). This could impact the system management and operations architecture. The regulations pertaining to cross-subsidy of different telco product lines will have to be carefully considered.

The new residential ADSL customers may accept a lower QoS for some of their applications (e.g. VoD) than say profit-critical business applications. However, it is unlikely that the telco would want to have two distinct levels of planning/deployment rules. They may chose to be more rigorous in their implementation for the high paying business customer but financial transactions in residential applications (e.g. home shopping) is likely to make them just as reliant on network integrity thus reducing scope for short-cuts. The QoS differentiation is more likely to manifest itself in terms of the use of test systems for rapid response to faults. Also, inherent network QoS differentiators such as ATM cell loss priority and degree of traffic overbooking (statistical multiplexing) can be exploited to justify higher business tariffs. The level of support from the service provider (as opposed to the network provider) may also be different. The telco may (although unlikely) consider zoning of the different customer bases (e.g. business parks) as a means of having a different tariff structure.

The availability of low priced mass market services, customer awareness and true plug and play user friendly applications will have a profound impact on the timing of this migration step for telcos. E.g. Can the customer now connect to an ATM based ADSL connection without needing to configure their PC for the appropriate VPI/VCI ?

Other differences to consider in moving the use of ADSL from business to residential includes the aesthetics of the remote unit and the number of boxes. Residential customers will have more onerous requirements. This could impact the preferred location of the POTS splitter and its accessibility, the degrees of freedom for locating the ADSL remote unit may be more constrained by the internal broadband and residential POTS extension wiring which is often less designed to be regularly changed or moved than in a business environment.

6.12 ADSL PLUS POTS TO ADSL PLUS 2ND LINE POTS

6.12.1 Starting Network Scenario

A customer has an ADSL-delivered service over their existing phone line and have a single POTS channel provided over the same line in the base-band frequencies below ADSL.

6.12.2 Target Network Scenario

The customer wants a second POTS line.

6.12.3 Drivers

A driver that could force a telco to consider this migration step is if their customer has a need for a separate line for the children, the so called Òteenager lineÓ Another driver is if the customer has started to work from home (telecommuting) and wants a separate line for a fax machine. The need for a second line could also arise if the customer is now running their own business from home and wants a second number for business purposes in order not to tie-up their own home number and also for billing separation.

6.12.4 Options & Issues

The first and most obvious option is for the telco to install a second copper pair to the customers premises. An alternative to this is to derive a 64 kbit/s duplex channel from the ADSL payload and add the necessary ringer and analogue interface circuitry to provide a digitally derived second line over the existing copper pair. Some of the techniques described in the section of this report covering DAML system migration issues may also be applicable here.

An impact of providing a second POTS line could be the need to re-wire some customer inside wiring, especially if the existing ADSL POTS splitter is in the NID, the NID may not be able to support some configurations.

There will be an impact on the telcoÕs records and test processes for the customer, particularly if one of the POTS channels is normal analogue base-band POTS and the other is digitally derived. This will also make it more complicated for the telcoÕs field staff to maintain the line. There could be training and tooling consequences.

The additional ringing crosstalk from the a second line needs to be considered so that it a configuration is used where it doesnÕt bypass the splitter and compromise ADSL performance.

6.13 FTTN & LONG-RANGE VDSL TO FTTK & SHORT RANGE VDSL

6.13.1 Starting Network Scenario

The telco has an access network based on the hybrid fibre/copper architecture of Fibre to the Node (FTTN) with long-range VDSL capable of operating over the last 1km/3000 ft of the customer connection.

6.13.2 Target Network Scenario

The telco deploys fibre deeper into the network to the kerbside resulting in use of shorter-range VDSL operating over the last 100-300m of the customer connection.

6.13.3 Drivers

The drivers that may encourage a telco to consider taking fibre closer to the customer and hence deploying shorter-range, higher-rate VDSL could include : An increase in demand for more bandwidth intensive services and applications such as HDTV. A high take-up of broadband services to the point where the FTTN ONU is fully utilised and there is no street space to place a second ONU (this is analogous to the way in which cable companies have subdivided their networks and moved HFC street units from 2000 customer serving areas to 500 customer serving areas). The telco may also see such a move as a stepping stone to FTTH. The use of shorter range VDSL may also be attractive to the telco where new developments occur and they need to extend the fibre and provide additional new ONUs to reach the new customer base.

6.13.4 Options/Issues

There are many key issues associated with such a migration step. An obvious one is the increase in operational costs due to the fact that there will be much more street electronics to install, operate and maintain. An evolution to a network with significantly more street electronics units will take a very long time and so the shift from FTTN to FTTK is probably only going to occur in isolated and localised areas where the additional bandwidth is really needed. There will be a time and cost impact of taking the additional fibre to the kerb, especially where duct space has been exhausted. The increased number of street units means more elements for the management systems to cope with and an increase in the size of associated network management databases. The smaller potential customer base sharing the costs of the ONU (e.g. 32 or 16 for FTTK as compared to say 300 for FTTN) will give the telco greater exposure to customer churn. The network for power feeding (and degree of maintenance on back-up batteries) will increase as the network now has more ONU nodes to power. This may impact the ability to integrate critical narrowband services (i.e. ÒlifelineÓPOTS) on the broadband network.

The initial location and hence subsequent accessibility of the FTTK ONUs needs to be considered. They may be pole-top or underground footway box units. These arenÕt as accessible as FTTN street ONUs and the environment is harsher. Underground units need to be sealed against moisture and power dissipation is more problematic. Pole-top units also increase the Òvisual pollutionÓ of the broadband network which may be unacceptable to some local authorities. In the liberalised Òdark copperÓregulatory environment that now exists in some countries (e.g. the USA), there will be an issue of which service provider installs there FTTK ONU on the customers copper drop-wire first. Can other service providers have access ? Are multiple units feasible given limited Òreal estateÓat pole tops and in man-holes/footway boxes ?

The customer interface on the remote VDSL unit may change in this evolution (e.g. from 12 Mbit/s or 25 Mbit/s to say 51 Mbit/s). This will have an impact or the customers ability to use their existing broadband CPE and broadband home wiring topology.

There could be major spectral compatibility issues for the telco to consider if long and short-range VDSL must co-exist in the same network. A degree of zoning would be possible and certain modulation and duplexing schemes can minimise the impact but it requires careful analysis and prudent use of planning/deployment rules. The telco must decide on the transmit PSD levels, bandwidth allocation of upstream and downstream and hence overall duplexing scheme (e.g. FDD or TDD) that it will use for VDSL and police this from the start. Some compromises (in terms of achievable bit-rate) may have to be made in the initial FTTN/VDSL deployment if FTTK is an anticipated next step.

6.14 FTTN/FTTK & VDSL TO FTTH

6.14.1 Starting Network Scenario

The telco has an access network based on the hybrid fibre/copper architecture of Fibre to the Node (FTTN) with long-range VDSL capable of operating over the last 1km/3000 ft of the customer connection or Fibre to the Kerb (FTTK) with shorter-range VDSL operating over the last 100-300m.

6.14.2 Target Network Scenario

The telco deploys fibre deeper into the access network all the way to the customers home/business.

6.14.3 Drivers

The factors that may drive a telco to consider migrating from hybrid fibre/copper to FTTH include : High take up of very bandwidth hungry services such as HDTV or multiple broadcast channels. FTTN/FTTK ONU is fully utilised with no space for modular expansion or a second ONU. A building may have been converted from a residential location to a business premise that has significantly greater bandwidth requirements and justifies FTTH/FTTB. A new development of a business park adjacent to say a residential area served by FTTN/FTTK and VDSL may also cause the telco to deploy FTTH to increase the range to reach the new customers. Alternatively, the new business customers may wish the additional security of FTTH which canÕt be wire-tapped.

The telco may have deployed FTTN/VDSL and considers FTTH as a cheaper next step than FTTK/VDSL due to the problems of increased numbers of street electronics. The telco may chose to deploy FTTH in certain locations to avoid RFI problems that some VDSL implementations may suffer from or cause. The telco may have experienced other technical or environmental problems in some areas where it has deployed FTTN or FTTK with VDSL (e.g. power dissipation/equipment heating, moisture ingress, vandalism of the ONU, complaints about the ONU size or location etc.) and FTTH could be a means of solving them.

In some parts of the world, the incumbent telco may wish to race ahead and spend capital on a FTTH deployment before they are subject to the commercial pressures of a fully liberalised telecommunications market and all capital spend will have to be more fully justified. This may involve making the most of any state subsidies or product line cross subsidisation whilst this is still possible.

6.14.4 Options/Issues

Among the many issues to consider in this network migration step are the impact on customer interfaces (and hence existing CPE and home wiring). What will be the impact on the customer of a new network termination box? Can the same interface be used on the VDSL remote unit and the FTTH delivery system (e.g. a 25 Mbit/s or 51 Mbit/s ATM interface)?. Where will the FTTH system be terminated? Is it inside or outside the house? Is the FTTH remote unit integrated with CPE and if so what are the standards and certification requirements? The skills, tools and time to install fibre in the home will have an impact on telco costs. It isnÕt yet as slick as terminating and routing copper wires around the home.

There will be a time and cost impact of taking the additional fibre all the way to the home, especially where duct space has been exhausted. A decision is required on how many fibres should be installed (for future proofing and/or resilience). Installation of a Òfibre drop-wireÓ the final connection into the home needs to be robust and cost-effective. Blown fibre techniques may find application here. A telco anticipating a move to FTTH sometime in the future can make the transition easier by using copper drop-wires today that include an integral small-tube bore. The final stage of the FTTH installation at some future date could then effectively blow the fibre into the home. The blown fibre technique has been successfully used already in the UK.

There will be less powering problems with the FTTH approach. However, with VDSL, the broadband network can be deployed as an overlay on top of an existing narrowband network with the narrowband services carried over copper at frequencies below VDSL. Moving to a FTTH network may force the telco to carry all services on the new broadband network. This has a major impact on operational systems and processes. For example, the location of faults in a FTTH network may require more extensive use of time-domain reflectometry (TDR) equipment and skilled personnel to operate it. The choice of point-to-point fibre or a passive optical network

(PON) will have an impact on the economics of the network and its fault-impact characteristics. In the liberalised Òdark copperÓ regulatory environment that now exists in some countries (e.g. the USA), there will be an issue of how to ÒunbundleÓ and resell capacity on the fibre to multiple service providers.

6.15 HDSL FOR INTERNET ACCESS TO ADSL FOR INTERNET ACCESS

6.15.1 Starting Network Scenario

The telco or ISP deploys HDSL (typically at 384 kbit/s or 784 kbit/s) over a single copper pair to provide high-speed Internet access.

6.15.2 Target Network Scenario

The telco or ISP deploys ADSL for faster Internet access.

6.15.3 Drivers and Issues

The telco or ISP may have originally deployed HDSL because of a perceived maturity in the technology and its price. Also, due to the high volumes of HDSL deployment in some areas it would be considered a proven technology with proven deployment processes, operational procedures, test equipment and known longer term performance and reliability. Where an ISP is initially deploying DSL over Òdry copperÓ, HDSL may be considered a safer option since if the local telco has previously deployed lots of HDSL lines themselves as part of their business as usual there can be no dispute over spectral compatibility issues.

The drivers that may lead to a migration to ADSL are firstly the greater downstream bandwidth available over a single pair. To deliver beyond 784 kbit/s or 1 Mbit/s using HDSL would require 2 pairs (or 3 with some E1 2 Mbit/s HDSL implementations). In addition, the use of ADSL allows POTS to be delivered over the same pair. If HDSL was used originally for Internet access then there must have been a second line into the home providing the telephony. Hence the migration to ADSL would permit the telco to sell a second POTS line to the customer. If the service was provided by a new service provider leasing dry copper, then they could bundle POTS and Internet access over a single leased pair using ADSL. ADSL would permit greater reach for a given downstream bit-rate. However, it should be noted that for really long lines HDSL can be repeatered (line powered from the CO). A repeatering option for ADSL does not exist.

There may be an issue in that in some networks, since HDSL has been deployed as part of a leased circuit (T1 or E1) or primary rate ISDN provision, the remote unit may be regarded as network equipment. However, ADSL remote units (particularly PC card implementations) may be considered as CPE. This may be a driver to migrate towards ADSL provisioning in that the equipment could be perceived as more mass market than HDSL with a greater variety of distribution outlets for purchase of the equipment.

Another issue in moving from HDSL to ADSL is that some implementations of ADSL will have a lower upstream data rate than is possible with HDSL. This could be important if the customer has been hosting their own web site and using the DSL system to send WWW pages ÒupstreamÓ. However, since the HDSL system would typically not be running much faster than 784 kbit/s and standardised and rate adaptive ADSL systems are capable of delivering 640 kbit/s upstream, this may not be a major issue.

6.16 IDSL FOR INTERNET ACCESS TO ADSL FOR INTERNET ACCESS

6.16.1 Starting Network Scenario

The telco or ISP deploys IDSL over a single copper pair to provide Internet access. IDSL (or ISDN DSL) uses the same 2B1Q transceiver technology as ISDN to transport data over around 18 000 feet of copper pair. However, unlike ISDN it does not get switched through the PSTN. Instead it the central office end (equivalent to a modem bank) would interconnect to the Internet via a router. Hence this technology is only used to carry data and canÕt deliver PSTN voice services.

6.16.2 Target Network Scenario

The telco or ISP deploys ADSL for faster Internet access.

6.16.3 Drivers and Issues

The telco or ISP may choose to initially deploy IDSL since it is based on a mature and proven transceiver technology that may be perceived as having reached its silicon cost floor. Also, since many operators are familiar with deploying Basic Rate ISDN, many of the planning processes and operational processes for IDSL will have been proven. In addition, much of the technology developed to support ISDN would also be applicable to support IDSL. This could include repeaters, test and commissioning equipment, terminal adapters, PC cards, routers and bridges with ISDN interfaces etc. In some countries the customer experience of getting ISDN installed has a reputation for being complex with the customer needing to know or find out details of the voice switch they are connected to. IDSL can be a simpler installation experience for the customer since technical knowledge of their PSTN switch connection is not required.

The telco or ISP may choose to initially deploy IDSL rather than ISDN for internet access to move Internet traffic of the PSTN voice switches to avoid traffic congestion problems. This may be particularly important where flat-rate billing for Internet access (as opposed to time-based billing) is to be used.

A driver to migrate from IDSL to ADSL would be the increased downstream bandwidth. ADSL should be able to deliver around 1.5 Mbit/s downstream over the longest of un-repeatered IDSL connections. There would however be a problem if the customer was on a repeatered line. In order for the customer to reap the benefits of the new ADSL access delivery system, other parts of the telco/ISP network may also have to be upgraded to ensure that there are no bandwidth bottlenecks further up the network.

If IDSL was used originally for Internet access then there must have been a second line into the home providing the telephony. Hence the migration to ADSL would permit the telco to sell a second POTS line to the customer. If the service was provided by a new service provider leasing dry copper, then they could bundle POTS and Internet access over a single leased pair using ADSL

IDSL is mainly targeted at Internet access and so migrating to ADSL would mainly involve a substitution by replacing the customers IDSL with ADSL. It should be noted that this may be in contrast to some customer situations where they had been using ISDN instead of IDSL. If they have CPE or applications that have been taking advantage of the ISDNÕs switched PSTN (e.g. video conferencing) then a different migration strategy may be needed (see section 6.4).

It should be noted that some implementations of IDSL embed the IDSL line card in a form of access multiplexor that enables simple upgrade of customers to ADSL (or HDSL) via replacement of the IDSL line card with an ADSL line card. However, there are other implementations that embed the IDSL line card in a standard D4 channel bank. In order to upgrade a customer from IDSL to ADSL it would be necessary to move them to a different access platform.

7. ANNEX A : WORK SCHEDULE

A.1	Project Initiation, Scope and Methodology Agreed	June 1996
A.2	Working Text Outline Agreed[4]	September 1996
A.3	Working Text 1st Draft Reviewed	December 1996
A.4	First Draft of Network Migration Working Text on WWW	January 1997
A.5	Final Draft of Working Text Sent Out for Straw Ballot	August 1997
A.6	Straw Ballot Issues Resolved	September 1997
A.7	Final Ballot Resulting in Technical Report Issued Before :	December 1997

8. ANNEX B : CONTRIBUTING MEMBERS OF WORKING GROUP

Acknowledgement is made to all of the attendees of the Network Migration working group meetings for their valuable contribution to discussions and brainstorming sessions that resulted in the content of this working text. The following individuals authored and or significantly reviewed the sections contained in the working text.

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[4] See "Proposed Outline for Network Migration Working Text", ADSLForum96-084, Gavin Young, BT, September 19th 1996 (London Meeting).

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9. Document History

Issue/Draft	Date	Editor	Comments
Draft A	Dec 10th 1996	G. Young	Presented as ADSLForum96-116 at Seattle meeting
Draft B	Jan 13th 1997	G. Young	Updated to include comments and results of brainstorming sessions at the Seattle meeting.
Draft C	Apr 18th 1997	G. Young	Updated to include comments and results of brainstorming sessions at the Amsterdam meeting.
Draft D	Jul 8th 1997	G. Young	Updated to include review comments and suggested improvements from the Boston meeting.
Issue 1	Oct 3rd 1997	G. Young	Changed from WT-013 to TR-004. Updated to include straw ballot comments and suggested improvements from the Brussels meeting.