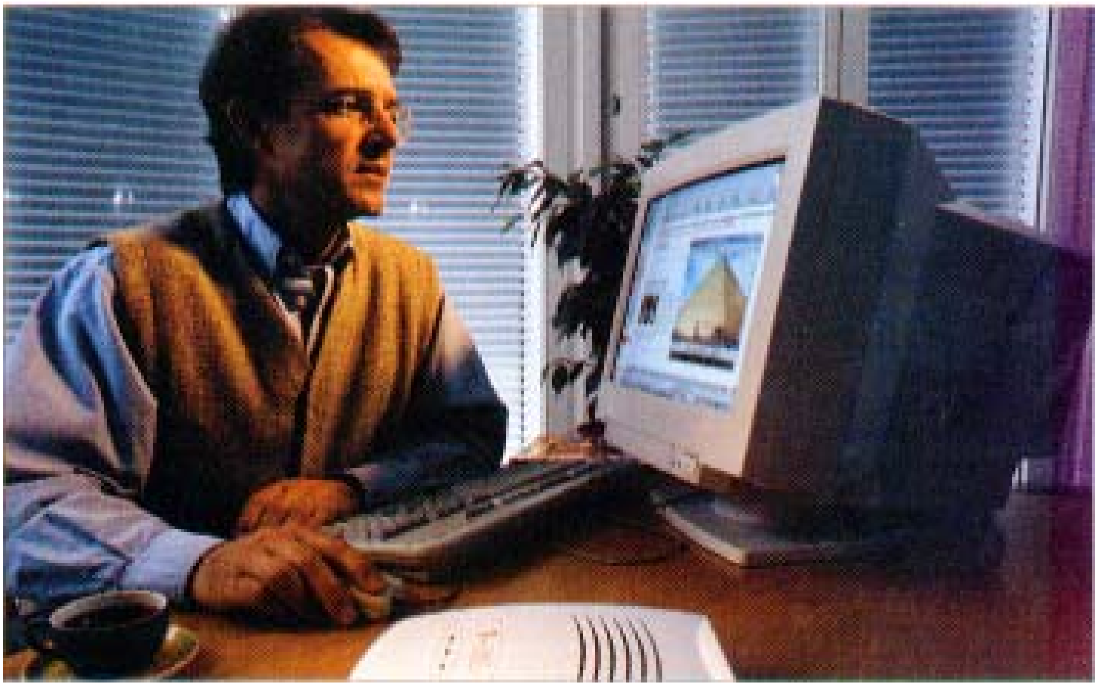
1 High-speed access gather space

The International Telecommunication Union (ITU) has approved a new Set of global standards for multi-Mbit/s network access via Asymmetrie Digital Subscriber Line (ADSL), the technology which squeezes more bandwidth from copper twisted-pair cables.
Systems based on the ITU recommendations are already being introduced in many countries to provide affordable access to Internet, teleworking and other broadband services at speeds many times faster than today‘s dial-up modems.
In Germany, for example, Deutsche Telekom plans to roll out 100000 ADSL lines this year (2000). In the UK, BT has come off the fence and is investing more than £250 million to provide an ADSL capability to 400 exchanges (there are 6000 nationwide) in 10 cities by spring 2000.
“These [ADSL] services answer the urgent need of telecommunications customers for instantaneous access to multimedia information,“ said Peter Wery, chairman of ITU Study Group 15, which drew up the ADSL standards. “The approval is well timed for equipment vendors and network operators alike.“



Wired up: Deutsche Telekom is among the European operators pioneering ADSL.

The ITU recommendations establish specifications for compatibhe systems that operate over a range of data rates from 1 Mbit/s to about 7 Mbit/s.
Wery added: “Work is already under way on potential enhancements [of the standards], including issues such as even higher bit-rates, increased loop reach and support of voice and data access for symmetrical and asymmetrical Operation.“
The emergence of high-speed access technologies like ADSL is one of the main reasons why telecoms companies are currently upgrading their core networks with dense wavelength division multiplexing systems.

2 ADSL: Viele Versuche, Fakten zu schaffen

Frust bei 3Com, Emsigkeit bei Siemens/Hemmschuh Telekom nutzt ungehemmt sein Quasi-Monopol

(tC, München/Jochen Ewe) Was die Versorgung der Geschäftswelt mit ADSL-Diensten (Asymmetric Digital Subscriber Line) betrifft, so kann von einem lupenreinen Alleingang der DTAG zwar nicht die Rede sein. Doch für Karl-Heinz Momm, Pre-Sales-Leiter in 3Coms Unternehmensbereich Carrier, ist dies nur ein schwacher Trost. Nicht einmal alternative Carrier in Deutschland haben bislang ADSL-bezogene Anfragen an 3Com gerichtet. Momm wörtlich: “Es ist ruhig.“ Weniger ruhig geht es bei den ADSL-Aktivitäten von Siemens zu.

3Com, das in Erwartung des DMT-Modulationsstandards (Discrete Multitone) sein ADSL-Produktangebot auf nur noch 3 Modellreihen reduziert hat, ließ in München vor Journalisten Frust erkennen:
ADSL-Geräte seien in den Geschäften “im Moment noch nicht zu sehen“ (Momm), und “die Produkte sind da, durchgetestet, interoperabel usw., aber in Deutschland bremst uns die Telekom massiv aus“ (Momm). Der “Hemmschuh Telekom“ (Momm) nehme durch seine Preispolitik alternativen Anbietern die Luft. Gefragt, ob er für 3Com in Deutschland überhaupt einen ADSL-Markt sehe, sagte Momm: “In naher Zukunft nein.“ Anders könne die Sache aussehen, wenn alternative Carrier ihre ADSL-Dienste beispielsweise via TV-Kabel anböten; die QoS-Mechanismen (Quality of Service), auf die man die Modems einstellen kann, gebe es jedenfalls dafür.
Eine weitere, wenn auch nicht unbegrenzt ausdehnbare Möglichkeit, sieht Momm darin, daß bestimmte Kunden ADSL in Backup-Netzen einsetzen. Wirtschaftlich attraktiv sei dies, weil außer einem zentralen Equipment nur die Modems in den einzelnen Lokationen ins Geld gingen. Zielgruppe sind für 3Com in erster Linie Abnehmer mit weitläufigem Werksgelände, “wo zumeist schon überall Kupferleitungen vergraben sind“ (Momm). In Deutschland hat 3Com derartige Netze bei Daimler-Benz und bei Shell realisiert. Firmen mit mehreren Standorten könnten diese Möglichkeit ebenfalls nutzen, wenn die Telekom ihnen ein Doppelkabel bereitstellt. Im übrigen sind bei allen diesen internen Nutzungen auch andere DSL-Techniken, nicht nur ADSL, einsetzbar.

Telekom früh im ADSL-Bereich

Im Juli hat die DTAG, ausgestattet mit den Erfahrungen aus einem einjährigen Pilotprojekt (s.u.), ihr ADSL-Angebot für breite Kundenkreise gestartet. Damit wird eine bis zu hundertmal schnellere Datenübertragung möglich sein, als ISDN sie bietet. Mit dem breitbandigen Internet-Zugang für Privatkunden ist die Telekom in Deutschland der Erste am Markt, begünstigt durch die Tatsache, daß sie. über die notwendige Infrastruktur, nämlich das Kupferkabel zum Endkunden, bereits verfügt. Auch im Weltvergleich gehört die Telekom zur ADSL-

Avantgarde; und 3Com-Mann Momm zeigte sich denn auch “überrascht, daß die Telekom relativ früh in den ADSL-Bereich eingestiegen ist - gerade auch mit Blick auf die USA.“
Zunächst werden den Telekomkunden in Hamburg, Hannover, Berlin, Dortmund, Düsseldorf, Köln, Bonn, Frankfurt am Main, Stuttgart und München ADSL-Anschlüsse angeboten werden. Noch bis zum Ende des laufenden Jahres will die Telekom dieses Angebot auf rund 40 Ballungszentren ausweiten und damit die Voraussetzungen für ca. 100.000 Kundenanschlüsse schaffen (bei einer Gesamtzahl von etwa 40 Mio. Kunden). Grund für die relativ kleine Zahl von ADSL-Abnehmern ist nicht nur die Preispolitik der Telekom (s. Kasten), sondern auch die Tatsache, daß nur 20 % der in den Kanalbündeln der Telekom verfügbaren Leitungen von ADSL belegt werden dürfen, soll es für die übrigen Netzdienste nicht zu Qualitätseinbußen kommen.
Die Telekom sieht sich, wie jeder ADSL-Anbieter, der Tatsache gegenüber, daß es einen international einheitlichen ADSL-Standard noch nicht gibt. Zwar hat sich die UAWG (Universal ADSL Working Group), der auch die Telekom angehört, auf einen Standard (ADSL lite bzw. G.lite) geeinigt, und seine Ratifizierung durch die ITU (International Telecommunications Union) steht unmittelbar bevor; doch die Experten zählen weltweit mindestens 40 derzeit laufende ADSL-Pilotprojekte, die mit unterschiedlichsten Standards operieren. Unter diesen Umständen ist das Versprechen des ADSL-Forums mit Vorsicht zu genießen, wonach “some of the UAWG‘s work will be continued“ - so Forum-Chairman Hans-Erhard Reiter -, wenn die UAWG planmäßig in einigen Monaten aufgelöst werden wird.
Möglicherweise aus diesem Grund hat die Deutsche Telekom von ADSL lite Abstand genommen. Ohnehin erlaubt die Lite-Version gerade mal ein Herunterladen von Daten mit 1,5 Mbit/s und kommt auf einen kärglichen “Upstream“ von 128 kbit/s. Der Vorteil von ADSL lite, keinen Splitter zu benötigen, wird von dem Risiko aufgewogen, daß eine per ADSL stattfindende Datenübertragung in dem Augenblick zusammenbrechen kann, wenn der Anwender einen hereinkommenden Anruf annimmt. Die Telekom entschied sich daher für die von der Bietergemeinschaft DeTeWe-ECI-Fujitsu-Orckit-Siemens entwickelte ADSL-Technik und wählte bei der Host-Technik einen proprietären Weg.

Erfolgreiches Pilotprojekt

Über einen der ersten ADSL-Feldversuche im öffentlichen Kommunikationsnetz, an dem sich seit Ende1997 die Telekom, die Universität Münster und Siemens beteiligt hatten, berichtet Siemens unterdessen, er sei nach dem Urteil aller Akteure erfolgreich gewesen. Siemens habe sich wie geplant aus dem Projekt zurückgezogen; die über 120 Münsteraner Teilnehmer jedoch wollten weiterhin den Hochgeschwindigkeitszugang zum Internet und zu den Diensten der Universität genießen. Die Telekom prüfe darum derzeit, das Projekt bis zu einer Überführung in ein Regelangebot fortführen. Schon jetzt hätten sich knapp 97 % der Testteilnehmer für die Weiternutzung der Technologie ausgesprochen, auch wenn zukünftig Nutzungsgebühren anfallen.
Siemens‘ ADSL-Zugangssystem “XpressLink D“, ein ATM-Breitband-Access-System, war bei dem Feldversuch von Februar 1998 an pausenlos voll beschaltet im Einsatz. Außer den 120 privaten Zugangspunkten in einem Studentenwohnheim in Münster hatte es die Anfragen von drei öffentlichen ADSL-Zugangspunkten zu bewältigen; denn von zwei “T-Punkt“-Repräsentanzen der Telekom und von der Mensa der Universität aus standen ADSL-Zugänge für jedermann zur Verfügung. Und während der CeBIT konnten sich Messebesucher über eine ATM-Verbindung von Hannover aus live an dem ADSL-Feldversuch beteiligen.
Rein statistisch hat sich die Nutzungsdauer pro Teilnehmer seit der Bereitstellung des ADSL-Zugangs mehr als vervierfacht, doch jeder 4. Testteilnehmer gab bei der anschließenden Befragung an, daß es häufig zu Engpässen bei der Nutzung des Internet gekommen sei.

Konnten die gewünschten Daten im Internet nur verzögert bereitgestellt werden, nutzte auch der Hochgeschwindigkeitszugang zwischen der Wohnung und der Vermittlungsstelle der Telekom nichts.
Die ADSL-Daten wurden bei dem Feldversuch mit acht Mbit/s über bereits vorhandene Telefon-Kupferkabel rund 1,3km weit zwischen dem Studentenwohnheim und der Vermittlungsstelle geführt. Selbst auf der über 4,3km langen Strecke zum räumlich abgesetzten Managementsystem konnten noch 4 Mbit/s übertragen werden. Die längste Verbindung war die zur Münsterlandhalle. Auf dieser rund 5,6 km langen Strecke konnten die Daten mit 2,5 Mbit/s störungsfrei übermittelt werden. Siemens berichtet, daß es in dem Kabelbündel zum Studentenwohnheim nicht zu Störeinflüssen in benachbarte analoge oder digitale ISDN-Leitungen gekommen sei.

G.lite-Tests in New Hampshire

Ungeachtet des guten Drahts zur Telekom und des von ihr eingeschlagenen ADSL-Wegs baut Siemens seine Position auch im G.lite-Umfeld aus und kommt ähnlich wie 3Com zu dem Fazit, daß die Produkte “da“ sind. Anlaß zu dieser Aussage geben die Resultate der Interoperabilitätstests, die vom UAWG-Konsortium im UNHIOL (University of New Hampshire Interoperability Laboratory) durchgeführt wurden. Mit diesen Tests, sagt Siemens, belegten die Hersteller die Eignung ihrer ADSL- und G.lite-Technologie und -Produkte für den sofortigen Einsatz im Massenmarkt.
An den Interoperabilitätstests, die im Mai 1999 durchgeführt wurden, beteiligten sich auf der DSLAM-Seite (Digital Subscriber Line Access Multiplexer) 15 Firmen, darunter Siemens mit XpressLink D. Auf der CPE-Seite (Customer Premises Equipment) waren es 26 Firmen mit insgesamt 31 Systemen (einige CPE-Firmen bieten mehrere Systeme an). Zu diesen 26 Firmen, die Modems in Form von PC-Karten anbieten, gehört auch Efficient Networks Inc., an dem Siemens eine Beteiligung erworben hat. Von XpressLink D aus wurden zu insgesamt 19 CPE-ADSL-Systemen anderer Hersteller stabile G.lite-Verbindungen aufgebaut.
Ziel der G.lite-Interoperabilitätstests war es, definierte Testschritte zu absolvieren und Anwendungen (z. B. Surfen im Internet) zwischen dem DSL-Modem eines Herstellers und dem DSLAM eines anderen Herstellers zu demonstrieren. Siemens testete erfolgreich die Interoperabilität mit Produkten der Hersteller Analog & Digital Devices Telecommunications, AMD, Globespan, Cayman, Integrated Telecom Express (ITEX), Texas Instruments, Lucent, Compaq, Flowpoint, Efficient Networks, 3Com, Alcatel Access Systems, Alcatel Microelectronics, Pairgain, Next Level Communications und Ascend Communications.

T - DSL

Mit T-DSL, wie die Deutsche Telekom ihr ADSL-Angebot nennt, erwirbt der Kunde für monatlich DEM 98 ein Paket, das aus T-Online (Internetzugang), einem ISDN-Anschluß (zwei Telefonverbindungen) und einem ADSL-Anschluß (dritte Telefonverbindung) besteht. ADSL gibt es nur in Verbindung mit ISDN. Die Telekom kann ADSL nicht auf Analoganschlüssen schalten. Auf den Erwerber kommen einmalige Kosten von DEM 100 für die Installation sowie von DEM 250 für die Bereitstellung des ADSL-Modems und des „Splitters“ zu. Der Splitter trennt die ISDN- von den ADSL-Signalen. Außerdem muß der Kunde eine ADSL-Netzwerkkarte erwerben (ab DEM 50), da ADSL mit der PC-ISDN-Karte oder mit Modem nicht funktioniert. Zur Internet-Nutzung bietet die Telekom verschiedene Tarifmodelle an, die alle eine Einwahlgebühr ins Internet von 6 Pfg. vorsehen.

- Symmetrische DSL – Technologie:
  HDSL (High Bit-Rate DSL; digitaler Anschluß mit hoher Bitrate)
  HDSL 2 (HDSL Anschluß des Typs 2)
  IDSL (ISDN DSL; digitaler ISDN-Teilnehmeranschluß)
- Asymmetrische DSL – Technologie
  Full Rate-ADSL
  UDSL (G.Lite) (Universal Digital Subscriber Line; Digitaler Universal-Anschluß)
  VDSL (Very High Bit-Rate DSL; digitaler Teilnehmeranschluß mit sehr hoher bitrate)
  BDSL (Broadband DSL; digitaler Breitband-Anschluß)

3 General Introduction to Copper Access Technologies

ADSL, VDSL, VADSL, HDSL, DSL, SDSL, BDSL -- enough for several dizzy spells. Most of these acronyms have relatively clear definitions, but they often suffer confusion, with one another and with other acronyms. (We must say that none will enjoy the fun of ATM, universally believed to mean Automatic Teller Machine, when we insiders know it really refers to that famous occult, Another Telecommunications Medium.)

This monograph hopes to define these terms. Rather than put them in alphabetical order, we have arranged them in chronological sequence of the basic terms, with synonyms, accidents, and a few related terms described briefly thereafter. We also eschew brevity. Glossaries often leave one panting for more. We hope to restore breathing with as little excess verbiage as possible, but with enough words to convey an impression of what a term really means, spiced up with a bit of history and a few application comments. A small table at the beginning summarizes the picture, and we relent at the end, with a terse, alphabetical Glossary.

Copper Access Transmission Technologies

Name	Meaning	Data Rate	Mode	Applications
V.22[1], V.32, V.34	Voice Band Modems	1200 bps to 28,800 bps	Duplex[2]	Data communications
DSL	Digital Subscriber Line	160 kbps[3]	Duplex	ISDN service Voice and data comm
HDSL[4]	High data rate Digital Subscriber Line	1.544 Mbps[5]	Duplex	T1/E1 service
		2.048 Mbps[6]	Duplex	Feeder plant, WAN, LAN access, server access
SDSL	Single line Digital Subscriber Line	1.544 Mpbs	Duplex	Same as HDSL plus
		2.048 Mbps	Duplex	premises access for symmetric services
ADSL	Asymmetric Digital Subscriber Line	1.5 to 9 Mbps 16 to 640 kbps	Down[7] Up	Internet access, video on demand, simplex video, remote LAN access, interactive multimedia
VDSL[8]	Very high data rate Digital Subscriber Line	13 to 52 Mbps 1.5 to 2.3 Mbps	Down Up[9]	Same as ADSL plus HDTV

[1] Designations are not acronyms, but CCITT recommendation numbers
[2] "Duplex" means data of the same rate both upstream and downstream at the same time.
[3] 192 Kbps divides into two B channels (64 kbps), one D channel (16 kbps) and link administration.
[4] A new system called SDSL, for Single Line DSL, operates at 1.5 or 2.0 Mbps duplex over one line
[5] Requires two twisted-pair lines
[6] Requires three twisted-pair lines
[7] "Down" means downstream, from the network to the subscriber. "Up" means upstream.
[8] Also called BDSL, VADSL, or, at times, ADSL. VDSL is ANSI and ETSI designation.
[9] Future VDSL systems may have upstream rates equal to downstream, but on much shorter lines.

4 Copper Access Technologies

We are quite used to voice-grade data modems, and their limitations. Voice grade modems presently transmit up to 28.8 kbps over a common telephone line, but the practical limit only twenty years ago was 1.2 kbps. No one believes we can go much faster than 33.6 kbps in the future, however. Voice grade bandwidth does not exceed 3.3 kHz. Modems like V.34 achieve 10 bits per Hertz of bandwidth, a startling figure that approaches theoretical limits. Not only that, V.34 modems transmit and receive simultaneously, in the same band. And you can buy one for under $200. We have these modems because of almost sublime advances in algorithms, digital signal processing, and semiconductor technology.

Voice grade modems operate at the subscriber premises end of voice grade lines and transmit signals through the core switching network without alteration; the network treats them exactly like voice signals. This has been their singular power, that, despite rather slow speeds compared to terminals today, they can be connected immediately anywhere a telephone line exists, and there are nearly 600 million such locations.

Bandwidth limitations of voice band lines do not come from the subscriber line, however. They come from the core network. Filters at the edge of the core network limit voice grade bandwidth to 3.3 kHz. Without filters, copper access lines can pass frequencies into MHz regions, albeit with substantial attenuation. Indeed, attenuation, which increases with line length and frequency, dominates the constraints on data rate over twisted pair wire. Practical limits on data rate in one direction compared to line length (of 24 gauge twisted pair) are:

DS1 (T1)	1.544 Mbps	18,000 feet
E1	2.048 Mbps	16,000 feet
DS2	6.312 Mbps	12,000 feet
E2	8.448 Mbps	9,000 feet
1/4 STS-1	12.960 Mbps	4,500 feet
1/2 STS-1	25.920 Mbps	3,000 feet
STS-1	51.840 Mbps	1,000 feet

Subscriber loop plant configurations vary tremendously around the world. In some countries 18,000 feet covers virtually every subscriber; in others, such as the United States, 18,000 feet covers less than 80% of subscribers. However, the 20% or so remaining have lines with loading coils which cannot be used for any DSL service (including ISDN) without removing the coils. Most telephone companies have had programs to shrink average loop length underway for a number of years, largely to stretch the capacity of existing central offices. The typical technique involves installation of access nodes remote from central offices, creating so-called Distribution Areas with maximum subscriber loops of 6000 feet from the access node. Remote access nodes are fed by T1/E1 lines (now using HDSL) or fiber. In suburban communities a Distribution Area connects an average of 1500 premises; in urban areas, the figure is double, about 3000 premises. Of course the number of premises served dwindles as service data rates increase. A Fiber to the Curb system (FTTC) offering STS-1 rates may only be within reach of twenty homes in some suburban areas.

You now have enough information to be a network planner, presuming the marketing department has handed you a stable list of applications. If that list does not include digital live television or HDTV (but does include video on demand and Internet access), then a data rate of 1.5 Mbps per subscriber terminal downstream may suffice, and you can offer it to virtually everyone within 18,000 feet, the nominal range of ISDN. For subscribers with shorter lines, either to a central office or remote access node, you can offer more than one channel to more than one premises terminal. If digital live television is on the list, then you have to offer at least 6 Mbps, and you may be limited to 4500 foot distances to supply more than one channel at a time. (This fact is the heart of telephone company interest in wireless broadcast digital TV, and the consequent Balkanization of its future network.) Clearly HDTV, demanding as much as 20 Mbps, only goes over the shortest loop length.

Of course, this offering of digital services over existing twisted-pair lines requires transceivers, special modems capable of dazzling data rates when one considers the age and original intentions of twisted-pair wiring technology. It turns out that this effort to use twisted pair for high speed information began many years ago.

DSL -- Digital Subscriber Line

The basic acronyms for all DSL arrangements came from Bellcore, so we must blame them for the basic confusion between a line and its modems. In general we say that DSL signifies a modem, or a modem pair, and not a line at all. Yes, a modem pair applied to a line creates a digital subscriber line, but when a telephone company buys DSL, or ADSL, or HDSL, it buys modems, quite apart from the lines, which they already own. So, DSL is a modem, not a line. This confusion becomes quite important to avoid when we talk about prices. A "DSL" is one modem; a line requires two.

DSL itself, apart from its later siblings, is the modem used for Basic Rate ISDN. A DSL transmits duplex data, i.e., data in both directions simultaneously, at 160 kbps over copper lines up to 18,000 feet of 24 ga wire. The multiplexing and demultiplexing of this data stream into two B channels (64 kbps each), a D channel (16 kbps), and some overhead takes place in attached terminal equipment. By modern standards DSL does not press any transmission thresholds, but its standard implementation (ANSI T1.601 or ITU I.431) employs echo cancellation to separate the transmit signal from the received signal at both ends, a novelty at the time DSL first found its way into the network.

DSL modems use twisted-pair bandwidth from 0 to about 80 kHz. (Some European systems use 120 kHz of bandwidth.) They therefore preclude the simultaneous provisioning of analog POTS. However, DSL modems are being used today for so-called pair gain applications, in which DSL modems convert a single POTS line to two POTS lines, obviating the physical installation of the second line wiring. The telephone company just installs the analog/digital voice functions at the customer premises for both lines, and presto, two from one.

T1 or E1

In the early sixties engineers at Bell Labs created a voice multiplexing system that first digitized a voice signal into a 64 kbps data stream (representing 8000 voltage samples a second with each sample expressed in 8 bits) and then organized twenty four of them into a framed data stream, with some conventions for figuring out which 8 bit slot went where at the receiving end. The resulting frame was 193 bits long, and created an equivalent data rate of 1.544 Mbps. The structured signal was called DS1, but it has acquired an almost colloquial synonym -- T1 -- which also describes the raw data rate, regardless of framing or intended use. AT&T deployed DS1 in the interoffice plant starting in the late sixties (almost all of which has since been replaced by fiber), and by the mid-seventies was using DS1 in the feeder segment of the outside loop plant.

In Europe, and at CCITT (now ITU), the collection of world PTTs other than ATT modified Bell Labs original approach, as they were wont to do, and defined E1, a multiplexing system for 30 voice channels running at 2.048 Mbps. In Europe E1 is the only designation, and stands for both the formatted version and the raw data rate.

Until recently, T1 and E1 circuits were implemented over copper wire by using crude transceivers with a self-clocking Alternate Mark Inversion (AMI) protocol. AMI requires repeaters 3000 feet from the central office and every 6000 feet thereafter, and takes 1.5 MHz of bandwidth, with a signal peak at 750 kHz (U.S. systems). To a transmission purist, this is profligate and ugly, but it has worked for many years and hundreds of thousands of lines (T1 and E1) exist in the world today.

Telephone companies originally used T1/E1 circuits for transmission between offices in the core switching network. Over time they tariffed T1/E1 services and offered them for private networks, connecting PBXs and T1 multiplexors together over the Wide Area Network (WAN). Today T1/E1 circuits can be used for many other applications, such as connecting Internet routers together, bringing traffic from a cellular antenna site to a central office, or connecting multimedia servers into a central office. An increasingly important application is in the so-called feeder plant, the section of a telephone network radiating from a central office to remote access nodes that in turn service premises over individual copper lines. T1/E1 circuits feed Digital Loop Carrier (DLC) systems that concentrate 24 or 30 voice lines over two twisted pair lines from a central office, thereby saving copper lines and reducing the distance between an access point and the final subscriber.

Note, however, that T1/E1 is not a very suitable service for connecting to individual residences. First of all, AMI is so demanding of bandwidth, and corrupts cable spectrum so much, that telephone companies cannot put more than one circuit in a single 50 pair cable, and must put none in any adjacent cables. Offering such a system to residences would be equivalent to pulling new wire to most of them. Secondly, until recently no application going to the home demanded such a data rate. Thirdly, even now, as data rate requirements accelerate with the hope of movies and high speed data for everyone, the demands are highly asymmetric -- bundles downstream to the subscriber, and very little upstream in return -- and many situations will require rates above T1 or E1. In general, high speed data rate services to the home will be carried by ADSL or VDSL (or similar types of modems over CATV lines).

HDSL -- High data rate Digital Subscriber Line

HDSL is simply a better way of transmitting T1 or E1 over twisted pair copper lines. It uses less bandwidth and requires no repeaters. Using more advanced modulation techniques, HDSL transmits 1.544 Mbps or 2.048 Mbps in bandwidths ranging from 80 kHz to 240 kHz, depending upon the specific technique, rather than the greedy 1.5 MHz absorbed by AMI. HDSL provides such rates over lines up to 12,000 feet in length (24 ga), the so-called Carrier Serving Area (CSA), but does so by using two lines for T1 and three lines for E1, each operating at half or third speed.

Most HDSL will go into the feeder plant, which connect subscribers after a fashion, but hardly in the sense of an individual using a phone service. Typical applications include PBX network connections, cellular antenna stations, digital loop carrier systems, interexchange POPs, Internet servers, and private data networks. As HDSL is the most mature of DSL technologies with rates above a megabit, it will be used for early-adopter premises applications for Internet and remote LAN access, but will likely give way to ADSL and SDSL in the near future.

SDSL -- Single line Digital Subscriber Line

On its face SDSL is simply a single line version of HDSL, transmitting T1 or E1 signals over a single twisted pair, and (in most cases) operating over POTS, so a single line can support POTS and T1/E1 simultaneously. However, SDSL has the important advantage compared to HDSL that it suits the market for individual subscriber premises which are often equipped with only a single telephone line. SDSL will be desired for any application needing symmetric access (such as servers and power remote LAN users), and it therefore complements ADSL (see below). It should be noted, however, that SDSL will not reach much beyond 10,000 feet, a distance overwhich ADSL achieves rates above 6 Mbps.

ADSL -- Asymmetric Digital Subscriber Line

ADSL followed on the heels of HDSL, but is really intended for the last leg into a customer's premises. As its name implies, ADSL transmits an asymmetric data stream, with much more going downstream to the subscriber and much less coming back. The reason for this has less to do with transmission technology than with the cable plant itself. Twisted pair telephone wires are bundled together in large cables. Fifty pair to a cable is a typical configuration towards the subscriber, but cables coming out of a central office may have hundreds or even thousands of pairs bundled together. An individual line from a CO to a subscriber is spliced together from many cable sections as they fan out from the central office (Bellcore claims that the average U.S. subscriber line has twenty-two splices). Alexander Bell invented twisted pair wiring to minimize the interference of signals from one cable to another caused by radiation or capacitive coupling, but the process is not perfect. Signals do couple, and couple more so as frequencies and the length of line increase. It turns out that if you try to send symmetric signals in many pairs within a cable, you significantly limit the data rate and length of line you can attain.
Happily, the preponderance of target applications for digital subscriber services are asymmetric. Video on demand, home shopping, Internet access, remote LAN access, multimedia access, specialized PC services all feature high data rate demands downstream, to the subscriber, but relatively low data rates demands upstream. MPEG movies with simulated VCR controls, for example, require 1.5 or 3.0 Mbps downstream, but can work just fine with no more than 64 kbps (or 16 kbps) upstream. The IP protocols for Internet or LAN access push upstream rates higher, but a ten to one ratio of down to upstream does not compromise performance in most cases.

So ADSL has a range of downstream speeds depending on distance:

Up to 18,000 feet	1.544 Mbps (T1)
16,000 feet	2.048 Mbps (E1)
12,000 feet	6.312 Mbps (DS2)
9,000 feet	8.448 Mbps

Upstream speeds range from 16 kbps to 640 kbps. Individual products today incorporate a variety of speed arrangements, from a minimum set of 1.544/2.048 Mbps down and 16 kbps up to a maximum set of 9 Mbps down and 640 kbps up. All of these arrangement operate in a frequency band above POTS, leaving POTS service independent and undisturbed, even if a premises ADSL modem fails.

As ADSL transmits digitally compressed video, among other things, it includes error correction capabilities intended to reduce the effect of impulse noise on video signals. Error correction introduces about 20 msec of delay, which is much too much for LAN and IP-based data communications applications. Therefore ADSL must know what kind of signals it is passing, to know whether to apply error control or not (this problem obtains for any wire-line transmission technology, over twisted pair or coaxial cable). Furthermore, ADSL will be used for circuit switched (what we have today), packet switched (such as an IP router) and, eventually, ATM switched data. ADSL must connect to personal computers and television set top boxes at the same time. Taken together, these application conditions create a complicated protocol and installation environment for ADSL modems, moving these modems well-beyond the functions of simple data transmission and reception.

VDSL -- Very high data rate Digital Subscriber Line

VDSL began life being called VADSL, because at least in its first manifestations, VDSL will be asymmetric transceivers at data rates higher than ADSL but over shorter lines. While no general standards exist yet for VDSL, discussion has centered around the following
downstream speeds:

12.96 Mbps	(1/4 STS-1)	4,500 feet of wire
25.82 Mbps	(1/2 STS-1)	3,000 feet of wire
51.84 Mbps	(STS-1)	1,000 feet of wire

Upstream rates fall within a suggested range from 1.6 Mbps to 2.3 Mbps. The principal reason T1E1.4 decided against "VADSL" was the implication that VDSL would never be symmetric, when some providers and suppliers hope for fully symmetric VDSL someday, recognizing that line length will be compromised.

In many ways VDSL is simpler than ADSL. Shorter lines impose far fewer transmission constraints, so the basic transceiver technology is much less complex, even though it is ten times faster. VDSL only targets ATM network architectures, obviating channelization and packet handling requirements imposed on ADSL. And VDSL admits passive network terminations, enabling more than one VDSL modem to be connected to the same line at a customer premises, in much the same way as extension phones connect to home wiring for POTS.

However, the picture clouds under closer inspection. VDSL must still provide error correction, the most demanding of the non-transceiver functions asked of ADSL. As public switched network ATM has not begun deployment yet, and will take decades to become ubiquitous, VDSL will likely be asked to transmit conventional circuit and packet switched traffic. (Indeed, a recent telephone company RFQ describes a VDSL-type transceiver with three circuit-switched video channels and a single ATM channel.) And passive network terminations have a host of problems, some technical, some regulatory, that will surely lead to a version of VDSL that looks identical to ADSL (with inherent active termination) except its capability for higher data rates.

VDSL will operate over POTS and ISDN, with both separated from VDSL signals by passive filtering.

Other Terms
VDSL had been called "VASDL" or "BDSL" or even "ADSL" prior to June, 1995, when T1E1.4 chose "VDSL" as the official title. The other terms still linger in technical documents created before that time and media presentations unaware of the convergence. ETSI TM3, the Euro-

pean counterpart to T1E1.4, has also adopted "VDSL," but temporarily appends a lower case "e" to indicate that, until the dust settles, the European version of VDSL may be slightly different than the U.S. version. This is the case with both HDSL and ADSL, although there is no convention for reflecting the differences in the name. The differences are sufficiently small (mostly surrounding data rates) that silicon technology accommodates both.

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Technical
Frequently Asked Questions

(last updated September 1998)

DSL-Lite / G.Lite

What is the ADSL Forum's position with regard to the proposed DSL-lite standard?
The ADSL Forum has appointed an official liaison to the Universal ADSL Working Group (UAWG), the consortium that is working on a G.Lite/DSL Lite standard. The ADSL Forum supports the UAWG's mission to create a universal, splitterless, and therefore easy to install lower-speed version of ADSL. Once the UAWG is disbanded, which is scheduled to happen either towards the end of 1998, or early 1999, its work will be incorporated and elaborated on by the ADSL Forum.

What speed range does DSL-lite support and is it compatible with the regular ADSL standard in terms?
At present, the exact specifications of a splitterless ADSL are still being discussed. The objective is to define a service that makes installation as easy as plugging an analog modem into a wall socket. DSL-lite makes the installation of a splitter (a filter that separates the frequencies normally reserved for POTS service) device on the customer premises side obsolete, and the service provider will not have to send out an engineer to the customer site. How compatible this service will be with other services, and under which speeds it will operate, has yet to be defined by the UAWG. However, it is clear that DSL-lite will not offer the full ADSL speeds, but operate at speeds of up to 1.5Mbit/s downstream.

BANDWIDTH

1) If I am on the phone, will that decrease my bandwidth when downloading and by roughly how much?
2) What do you mean by Asymmetric?

1) Voice communications over POTS (plain old telephone service) operates at frequencies below 4KHz; all other services, such as ADSL, will use the frequencies above that. So no matter whether you are using the POTS frequencies or not, the bandwidth available to ADSL is not affected.
2) ADSL is asymmetric in that it transmits data faster downstream than it does upstream. This is appropriate for surfing the Internet, for example, where large amounts of data are transferred from the network to the user, and much less data is passed back to the network. Traditional systems, like most modem connections, have been symmetric. ADSL usually has a downstream rate that is approximately 10 times faster than the upstream speed, but some ADSL offerings today deliver the same speed bidirectionally, e.g. 384kbps bidirectional.

ADSL boasts a great bandwidth. Can it be shared among two or more PCs, so that both can be connected to the internet at the same time?
Yes. If the modem has one, or multiple Ethernet 10baseT interfaced, it can connect an entire LAN. That way, all users on the LAN can share the higher connected bandwidth. If the mo-

dem has only one 10baseT interface, you can connect it to a mini-Ethernet hub which will distribute the bandwidth over a LAN.

What is the bandwidth requirement for an ISP who wants to offer ADSL? Will this ISP be able to keep its T1's or will they have to get an OC-3 (45 Mbit/s) or higher?

The bandwidth requirement will depend upon the number of users, their estimated usage patterns, user bandwidths (depends if user is given a fixed bandwidth and what it is) and the estimated statistical multiplexing gain. The calculation would be similar to that which has to be made for and existing ISP trying to calculate number of ports, telephone connect speeds, etc.

BOOKS on DSL
Can you recommend some good books/papers about ADSL/ISDN and ist development/evolution from an application point of view (user-benefit!) and the operator point of view? The books should present more of a comprehensive overview of how ADSL and other xDSL technologies are positioned.

Here are some publications on DSL worth looking at:
- Virata's primer, Personal Broadband Services: DSL and ATM, translates the complexities of the various xDSL technologies into language that is easy to understand. Please go to http://www.virata.com/broadband.html to download a copy in PDF format.
- DSL, by Walter Chen. Published by MacMillan Technical Press. You can find the ISBN number from Amazon's web site. A good technical book covering the various DSLs.
- Residential Broadband, by George Abe. Published by Cisco Press. Reasonable overview.
- ADSL and DSL Technologies, by Walter Goralski. New York (McGraw-Hill), 1998.
- Demystifying ATM/ADSL, by Michael Busby. Published in 1998
- DSL: Specialization Techniques and Standards Developments for Digital Subscriber Lines, by Walter Chen. Published in 1998.

COPPER CABLE INFRASTRUCTURE

Many telco's have various guages of cable serving an area. In many cases, several types and guages of cable are run together to provide service to an area. How will ADSL perform when this situation is presented? Do you have any charts or calculations that are used to reflect ADSL functionality when this problem is present?

The ADSL Forum does not have calculation charts. Different ADSL vendor products using different line codes may have very different performance. ADSL products designed to the ANSI Standard T1.413 for ADSL are designed to operate on a variety of test loops which include loops with such multiple segments. The most popular cable guages are 24 AWG (~0.5 mm) and 26 AWG (~0.4mm) and hence these are most commonly represented. We would expect that the highest performing ADSL products would operate on these cable guages. Bear in mind that some manufacturers of loop qualification equipment are also offering products that can provide such a pre-qualification test.

One thing that I really like about cable modem is that you don't have to dial-in. That means that you don't have to hook onto any line. You just start your IE and everything starts, no "line-busy" messages etc., no extra phone bills or any extra international traffic charges. Am I right?

Although today's voiceband modems are dial-up (circuit switched) services, ADSL based services will be "always connected", just like a LAN or a cable modem. The ADSL modem operates simultaneously with the phone, so that regular telephone service can continue unaffected by the modem (unlike today's modems). Furthermore, since each ADSL customer has its own dedicated copper line, throughput is unaffected by neighboring users. Thus it does not suffer the disadvantage of a cable modem where multiple users sharing a common coaxial cable network will reduce the speed available to each user (the capacity has to be shared across all users). No per-minute charges are incurred, unlike some dial-up services that charge by the minute.

CABLE MODEM SERVICES

My cable company has indicated in a news bulletin that soon they will be introducing Internet Access at speeds 50 times that of a 28.8 modem. The cost to subscribers will be $39.00 per month and there will be an installation charge of several hundred dollars. They call it broadband. Is this the same as ADSL?
No. ADSL works over telephone lines. This sounds like a cable modem. It operates over your cable network by digitizing some of the bandwidth and using it for data traffic instead of TV. Bear in mind that the maximum data rates often quoted may not be guaranteed. Thus when many people are using the network of cable modems, they may have to share capacity, and therefore the speed that each user experiences may reduce significantly. With ADSL, since each customer is using their own dedicated copper wire, access speed and bandwidth is independent of how many of your neighbors access the Internet.

Can ADSL be a valid alternative to HFC regarding Cable-TV transmission? How many TV channels could be carried by ADSL in addition to Telephony and Data?
ADSL runs at downstream speed up to 8 Mbit/s. That leaves room for broadcast applications, which need typically 4 Mbit/s. Then remote channel change in the CO is envisaged, making the number of channels accessible infinite. Only the channel selected by the user is actually carried over the ADSL line.

ECHO CANCELLATION

I'm doing research on the technologies actual and future for the local loop, especially the DSL family. For ADSL systems, I know that two kinds of multiplexing are used : FDM Frequency Division Multiplexing and the echo cancellation. I would like to know how the echo cancellation is implemented.
In simplest terms, echo cancellation means that the upstream and the downstream signals are sent on the wire at the SAME frequencies, i.e. they overlap, whereas FDM method sends the upstream and the downstream separated at different freqs. The advantage of echo cancellation is that the signals are both kept at the lowest possible frequencies (since cable loss and crosstalk noise both increase with frequency) and therefore achieves greater cable distance for a given data rate. However echo cancellation ADSL systems are more complicated, and only a few vendors have implemented them. (It is an option - Category 2- in the ADSL Standard). An ADSL receiver will see an incoming signal that is both the incoming signal from the far end and the outgoing signal from the local transmitter. These are mixed together at over the same frequency range. In other words, the received signal composes of not only the signal to be recovered from the far end but also a local echo due to the local transmitter. The local echo must be accurately modeled by DSP circuitry and then this replica echo is electronically subtracted from the composite incoming signal. If done properly then all that is left behind is the incoming data from the far end ADSL system. The process of modeling the echo is quite complicated since the echo varies depending on the connected cable

type. The DSPcircuitry automatically adapts to account for this. Exact details of the DSP implementation will vary with vendor.

ISDN

If one compares ISDN with ADSL and if my target population is a home user, which one will succeed in the market today if you take the speed, cost and technical difficulties into consideration?
The ADSL Forum is unable to make market forecasts. However we believe that ADSL has strong future due to 3 key reasons:
(1) The additional speed available from ADSL
(2) Its ability to share an existing telephone line with a standard voice line
(3) ADSL networks (unlike ISDN) bypasses the telephone switches, that today are overloaded with data traffic. Future availability of ADSL will depend on the deployment by local telephone company.

Will ADSL need separate lines like ISDN and will the lines have a monthly fee like ISDN?
ADSL is able to operate on a line simultaneously with the telephone. A new separate line does not need to be installed. This is one of the big advantages. The pricing policy will vary from provider to provider and also depend on exactly what level of service is being offered. Most service providers are tariffing ADSL based on a single monthly tariff with no per-minute-charges.

ISP's/TELCOS

Do users still need telcos to effect any modifications at the exchange switch? In other words, do we need the telco's active participation, or can we implement ADSL for our own use?
The bottom line is that you need access to copper lines. If you are an incumbent telco then of course you have copper already. If you are not a telco then you must gain access to copper. In the USA this can be done by leasing an unbundled loop (i.e. a dry copper wire is leased by the telco to you, then you can apply ADSL equipment). An ISP can do this, but in order to lease it at wholesale prices one needs to file and become a Competitive Local Exchange Carrier (CLEC). An ISP would actually need to lease a copper wire that runs from a customer to its Point-of-Presence (POP). If you leased only a wire that runs from customer into the Central office building, then you would need to install your ADSL equipment within the CO building. Since it is owned by the telco, you would have to lease a co-location space.

Once ADSL is available around the country, does it work in the same way as access now? I've read where we would pay the phone company for access, if that is so, would one still need an ISP, or does the ISP contract with the telephone company, and then re-sell access to us?
The phone company provides access to the network and needs to be paid. Therefore, you can still connect to the ISP of your choice, however, the phone operator may be an ISP itself (which is getting more and more common these days).

What would an ISP need to have to start offering ADSL to it's customers, just a new modem rack or is there other hardware involved? And of course our local phone company would have to have ADSL also, correct?
The equivalent to a modem rack for ADSL is something called a DSLAM (Digital Subscriber Line Access Mux) which is a rack of ADSL line cards with data multiplexed into a backbone network interface/connection (T1, OC3 DS3, ATM or Frame Relay). This would usually reside in the CO due to the limited transmission range of ADSL. This DSLAM could be owned by the ILEC and capacity leased by the ISP or owned by a CLEC where unbundled access is avai-

lable. The backbone from the DSLAM in the CO would then connect into the ISP router at their PoP.

LEASED LINE

What is the difference between ADSL and the normal leased line? I intend to hook up my LAN with 300 computers to the Internet, the normal practice is use a leased line, but can I use ADSL if my ISP has that technology and service? And is there any performance trade off or bottleneck compared to the leased line solution ?
ADSL is just another way of transporting the data bits. So yes, it can be used to provide a leased line. In fact in its symmetrical form (i.e., HDSL) that is the primary interest and today it is used for just that. Since ADSL is asymmetric it can be used to provide a leased line that is asymmetric (and hence differentiated from existing T1 tariffs). Thus the telcos can introduce ADSL without too quickly cannibalizing existing T1 (symmetric) services. In these cases the leased line is effectively nailed up to an ISP and maybe the ISP monthly tariff is also thrown in, so the total package is instead sold as high speed internet access.

LOAD COILS

I was recently turned down to participate in an ADSL trial with BellSouth. The problem is that there is a load coil somewhere which prevents the proper operation of the ADSL modem. How hard are load coils to move, and does this mean I will never have ADSL?
Load coils were used on voice lines to improve the quality of the voice service. Typically they are inserted at 3000 ft intervals along the line. While they improve (flatten the response) the voice service, unfortunately they do not allow any signals above the voice band 0-4kHz to pass through them. Since all types of DSL (ISDN, HDSL, SDSL, ADSL, VDSL) use frequencies well above the voice region, they prohibit the use of DSL technology. This has been the case with ISDN deployments and HDSL deployments over the past few years. Most telcos have a process where the load coil is removed the line. It is a pain, and a cost overhead, but need not be a showstopper. It would be interesting to know if you would qualify for ISDN service; since it is normal in most regions for the coils to be removed for ISDN requests.

NOISE INTERFERENCE

I don't understand why data transfer has to be asymmetric with ADSL technology. I understand that there is interference between two lines, but I don't understand how asymmetric data transfer can reduce this interference?
Crosstalk causes by far the largest contribution to capacity limiting noise for xDSL systems. There are two very different types of crosstalk in multi-pair access network cables, Near-End Crosstalk (NEXT) and Far-End Crosstalk (FEXT). NEXT is interference that appears on another pair at the same end of the cable as the source of the interference. Its level is substantially independent of the length of the cable. FEXT on the other hand is interference that appears on another pair at the opposite or far end of the cable to the source of the interference. Its level is attenuated at least as much as the signal itself if both have traveled the same distance. NEXT affects any systems that transmit in both directions at once (e.g. echo-cancelling systems), and where it occurs it invariably dominates over FEXT. It limits ISDN & HDSL range. NEXT can in principle be eliminated by not transmitting in both directions in the same band at the same time, separating the two directions of transmission either into non-overlapping intervals in time or into non-overlapping frequency bands. This converts duplex transmission into independent simplex transmissions, avoiding NEXT at the cost of a reduced bandwidth in each direction. FDM ADSL avoids NEXT in this way. At high enough frequencies the advantage of transmitting against FEXT noise rather than NEXT noise becomes so great that it can outweigh the disadvantage of reduced bandwidth.

POINT-TO-POINT LATENCY

What is the point-to-point latency between the ADSL modem at the customer site and the hub/modem on the other end? Is it the same as that of a dedicated connection like a T1/T3/Etc (0ms). or is more like that of modem technologies (130-150ms)?
The latency between the customers ADSL modem at the ADSL line card in the CO depends on the line coding technique and the interleaving depth of the error correction scheme. The interleaving depth can programmable up to latency of the order of 60 ms but is typically set to around 20 ms. This offers greater protection against impulsive noise and thus improved BER. Hence there is a latency/interactivity versus error performance trade-off. With the interleaver turned off the residual latency of standard ADSL is 2 ms. Some other modulation schemes can achieve less than this. Other parts of the system and ADSL above the physical layer must also be accounted for, e.g., ATM SAR function, router throughput, etc.

POTS

What is the guard band separation between the voice POTS channel and the data channel? Does the POTS support the signaling used today with -48vdc?
ADSL typically starts at around 25 kHz so the POTS splitter can use the 4 kHz to 25 kHz band as a transition band. And yes, a good splitter design can support MF tone & loop dis signaling.

SIZE

How many megabits of data would pass through the lines in a normal internet phone conversation of about 10 minutes, as compared to the normal 56 kbp modem?
Voice on IP is an application. ADSL can allow to run with higher quality is application allows for this. ADSL can run up to 640 kbit/s upstream. So about 10 times faster.

SPEED

I understand that you can have about 100 users connected to a T1 line before the speed of the line starts to drop down. How many users can you connect to an ADSL line before the speed will drop off? I am wondering whether you could setup a web server that had heavy traffic with an ADSL line.
You may be confusing two separate issues. The "100 users to a T1 line" statement is an example of the typical number of ADSL links that can be concentrated onto a single T1 backbone connection. It is based on the premise that not every one is downloading at the same time, and therefore many ADSL lines can share a T1. Similar to a corporate office that may have 100 users (at their desk) all connected onto a single T1 line, and each experiencing pretty fast service. Various industry experts believe that this concentration model works ok for normal small, home and corporate business usage profiles. Very intensive users may demand a lower level of concentration (perhaps 50 per T1) and this of course will increase the costs since the T1 connection to the internet is now shared over less users. The other question, often asked, is how many users (e.g., PCs) can I hang on the (customer) end of an ADSL line. For down stream performance, since the ADSL modem has similar capacity to the T1 connection, it is as if the ADSL was not there, and any second or third users on the customer premises end, can be counted as additional users, in the method above. The only noticeable issue is for upstream transmissions, where multiple users at customer end are having to share small upstream capacity.

What are the ping times for ADSL? For example, let's say I have a great ISP and want to play QuakeII or other games, what kind of ping would I get? I have about 200-300 ms normally with a modem and good ISDN connections give me lower than 50 ms.
ADSL delay time is variable and depends on the interleaving that is programmed. It varies from 2 - 20 msec each way. Hence worse case round trip delay added would be 2 x 20 msec = 40 msec.

What are the speeds for T3 and OC3? Also, I have read in some places that the upstream for a ADSL line can be improved to 1000 kbps or 1 Mbit/s. Is this possible?
T3 is a synonym for DS3 service, which is approximately 45 Mbit/s, and OC-3 is approximately 155 Mbit/s fiber interface. Some vendors provide upstream ADSL speeds that exceed the 604 kbps of the ANSI T1.413 standard. You should check directly with the various ADSL equipment vendors. Often, this extra upstream speed is provided at the expense of stream speed and is targeted on less asymmetric applications where maximum (e.g., 6 Mbit/s) downstream speed is not required, and more upstream speed would be useful.

STANDARDS

With regards to the convolutional interleaver in the ADSL modem, I would like to find out what specifications have been outlined for this and its proposed method of implementation?
ANSI ADSL standard T1.413 has details on this. Refer to the ANSI T1E1.4 home page for more information on ANSI standards, etc.

VIDEO

What does the compression of the ADSL do the resolution of the video images?
ADSL is simply a date pipe and can be used to carry, amongst other things, video images that are already compressed. Today's video compression technology is such that it demands about 1 megabit for VCR quality pictures and 2-3 Megabits for broadcast (superb) picture quality. (For example DirectTV satellite systems use about 3-4 Mbit/s.) ADSL can support up to 6 Mbit/s per second and is therefore able to carry at least one such video channel.

Is it true that there is always transmission imperfection with datasand videos, and that HDSL was set for videos, not ADSL? If so, is it still possible to have good quality (VCR quality) with video transmission on ADSL? How?
It is true that there are transmission imperfections with any DSL. This is true of every type of transmission system, including wireless, coaxial etc. Typically an error rate of 1 in 10,000,000 bits or higher is achieved. However, the situation is indeed the opposite to that which you describe. HDSL was designed for replacement of the T1/E1 repeater systems. ADSL was designed originally for video on demand (VoD). Since VoD uses compressed video, it is much more sensitive to errors, and therefore ADSL was designed to cope with this. To ensure very low error rates, extra features were added to ADSL, such as interleaving and error protection coding at the expense of a small time delay (5-20 msec depending on settings). ADSL is therefore very able to achieve video transmission. This has been proven in various trials worldwide over the last few years. Indeed, at the higher data rates >4 Mbit/s, the picture quality is much better than "VCR", and indeed exceeds that of many cable installations

MISCELLANEOUS

Is it possible to carry voice and data together to an ATM network from the DSLAM, instead of splitting the voice and submitting it to a class 5 Voice switch?

Once voice over ATM is widespread & the delays are acceptable this could be done. It would also be a neat way of providing a second voice line.

Does ADSL suffer from the same problem as the Nortel/Norweb (IP over Powerlines) insofar as it is Radio Frequency leaky? Doesn't the FCC have something to say about it? Or is my information false?
ADSL is designed to transmit its signal in the differential or transverse mode on the two copper wires forming the pair. It is not designed to transmit in the common mode which is the case for some powerline system designs. Also, the copper phone cable balance that can convert differential mode to RF emitting common mode is pretty good at ADSL frequencies.

Is it possible to use ADSL with laptops?
The work in the UAWG and ITU to specify a splitterless form of ADSL known as DSL-Lite seeks to enable the ADSL to be plugged into a phone socket like a modem. There could be two manifestations of this. One would be a DSL-Lite modem on a NIC card in the PC. Another would be an external modem, perhaps with a USB interface to the laptop. The latter would appear to be the most appropriate way of using DSL-Lite with a laptop in the short term. Standards aren't completed for this yet but the UAWG and ITU are working on it. You'd need to be plugging into a phone socket that is short enough for DSL transmission and where the local CO is wired for ADSL.

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ADSLForum TR-002

ATM over ADSL Recommendations

March 1997

ABSTRACT

This technical report describes interfaces and system configurations for ATM transported over Access Networks based on Asymmetric Digital Subscriber Line (ADSL) technology.

TABLE OF CONTENTS

1) Statement of the Project.

1.1) Scope

This technical report addresses implementation aspects specific to the transport of ATM over Access Networks based on Asymmetric Digital Subscriber Line (ADSL) technology.

The scope for the first issue of the report is to provide a specification for the transport of ATM over ADSL that is consistent with the ANSI T1.413 standard 1995 [2]. Future issues of this technical report will seek to preserve backward compatibility with this document. The report aims to provide comprehensive guidelines for the selection of bearer channels for the transport of ATM and to provide clear interpretations of the pertinent sections of the ANSI T1.413 standard [2].

Future issues of this specification will address the generic (line code independent) requirements on the ATM-TC to ATM layer interface.

As the ADSL Forum is line code neutral, TC variations required for other specific line codes will be addressed in future versions of this document.

This specification provides a detailed Transmission Convergence (TC) sublayer specification that can be used with the ANSI T1.413 standard 1995 [2], and provides outline descriptions of the Access Node and Network-Termination (NT) functions. In later issues, effort will be made to provide more detailed functional descriptions.

This report concentrates on ATM network layer protocols up to the ATM layer; higher layers are considered to be transported transparently by the ADSL based access network. Interfaces towards both the Local Exchange and towards Premises Distribution Network are covered. All configurable parameters and a means for managing their configuration are defined.

With reference to figure 1 below, it is the intention of this report to describe the functional blocks of the ADSL based access network from the Vc interface to the T (or other) interface, and not to specify the physical level of the interfaces.

2) Specific Reference Model.

Notes:
1. Although the above figure shows two paths ("Fast" and "Interleaved"), it is only mandatory to implement a single path. Dual latency is strictly optional. (See section 3.2).
2. The functional groups Broadband NT1, B-NT, B-NT+TA and B-NT+TE and the reference points T, S and R are defined in ITU-T recommendation I.413, B-ISDN User-Network Interface [9].

Figure 1: Specific reference model for ATM Mode.

2.1) Definition of Functional Blocks.

Access Node.

The Access Node performs the adaptation between the ATM Core Network and the Access Network. In the downstream direction it may perform routing/demultiplexing, while in the upstream direction it may perform multiplexing/concentration.

B-NT1, B-NT, B-NT+TA or B-NT+TE.

This functional block performs the functions of terminating the ADSL signal entering the user's premises via the twisted pair cable and providing either the T, S or R interface towards the terminal equipment. Such an interface may be absent in the case of integration of the functional block with the Terminal Equipment. Its functions are: terminating/originating the transmission line, handling the transmission interfacing and OAM functions. In addition, it may optionally include routing/multiplexing of the "Fast" and "Interleaved" flows.

ATM layer functions.

In the Access Node this function performs in the downstream direction routing/demultiplexing on a VPI and/or VCI basis, while in the upstream direction multiplexing/concentration, again on a VPI and/or VCI basis.

If implemented in the B-NT1, B-NT, B-NT+TA or B-NT+TE, this function performs cell routing/(de)multiplexing to the "Fast" or "Interleaved" channel in the upstream direction and routing/(de)multiplexing of the two flows into a single ATM stream per T interface instantiation in the downstream direction.

TC ATM Transmission Convergence sublayer functional block.

ATU-C ADSL Transceiver Unit at the Central Office end.

ATU-R ADSL Transceiver Unit at the remote terminal end.

3). Transport of ATM over ADSL.

3.1) General

Transport classes and bearer channel rates based on multiples of 1.536 Mbit/s are considered to be inappropriate for the transport of ATM. Sections 5.1.3 and 5.2.3 of the ANSI T1.413

standard [2] are superseded by this document. For the transport of ATM on modems compliant with ANSI T1.413 standard, channels shall be independently set to any bit rate that is an integer multiple of 32 kbit/s, up to a maximum aggregate capacity determined by the start-up process. In addition, for each channel the bit rates for the upstream and downstream directions may be set independently from each other.

3.2) Channelisation

For ATM systems the channelisation of different payloads is embedded within the ATM data stream using different Virtual Paths and/or Virtual Channels. Hence, the basic requirements for ATM are for at least one ADSL channel downstream and at least one ADSL upstream channel.

The ANSI T1.413 standard [2] gives the possibility to use both the "Interleaved" and "Fast" paths for services with requirements for either high error performance or low latency respectively. The real need for this dual nature for ATM services depends on the service/application profile, and is yet to be confirmed. Consequently, different configurations of the ADSL access could be considered. More specifically, possibly three "latency classes" could be envisaged: Single latency, not necessarily the same for each direction of transmission. Dual latency downstream, single latency upstream. Dual latency both upstream and downstream.

For the transport of only ATM over ADSL, all modems shall use the AS0 channel downstream and the LS0 channel upstream for the single latency class. Channels AS1 and LS1 are reserved for dual latency. The dual latency option will be specified in a future issue of this

document.

A ³hybrid² implementation of one or more Bit Synchronous (Plesiochronous) channels together with the ATM channels is not precluded by the above. The bandwidth occupied by the Bit Synchronous channel must first be reserved before allocating the remaining bandwidth to the ATM channel.

Note: In accordance with the channel allocation above, it is mandatory for compliance with these recommendations to implement at least one single path, either via the fast buffer or the interleaved buffer.

3.3) Protocols

With respect to the protocol reference model for B-ISDN [5], only the Physical Medium Dependent (PMD) and Transmission Convergence (TC) sublayers of the physical layer and the ATM layer are relevant to this report.

Figure 2 shows the protocol layers for the specific reference model given in figure 1. In this example, T interface supports ATM. Non-ATM interfaces are also possible, but not discussed in this report.

Figure 3: Protocol layers.

4). Quality of Service (QoS).

4.1) Data Rates

Modems compliant to ANSI T1.413 standard can be programmed to provide bearer channel data rates which are multiples of 32 kbit/s. This facility may be exploited for the transport of ATM. Channel data rates can be set on a semi-permanent basis depending upon the loop characteristics for the paticular user. Complete flexibility is therefore given to the Network Operator.

4.2) BER

ANSI T1.413 standard [2] specifies a BER of 10-7 with a 6dB margin.

The Network Operator may decide on a BER/ Latency/ Range combination that meets the required service quality for the network.

The effect of ADSL performance impairments on ATM performance is for further study.

5). System Issues.

For a future issue of the document.

6). Description of Functional Blocks.

6.1) Access Node ATM Layer Functions.

In the downstream direction this block performs cell routing on a VPI and/or VCI basis to the appropriate ADSL modem and optionally to the "Fast" or "Interleaved" TC sublayer of that modem. In the upstream direction the cell streams are combined/concentrated to form a single ATM cell stream.

6.2) Transmission Convergence (TC).

6.2.1) Access Node TC

6.2.1.1) General

The ATM Transmission Convergence Sublayer is based on ITU-T recommendation I.432 [3]. There is no specific relationship between the beginning of an ATM cell and the ADSL frame. The transmitter can transmit the cell octets aligned to any bit in the ADSL octets. The receiver shall assume no alignment between ATM cell octets and the ADSL octets. The functions are described in the sub-sections below. The transmission order of the bits is as shown in I.432 [3] for SDH; i.e. the Most Significant Bit (MSB) of each byte is sent first.

6.2.1.2) Header Error Control

Header error control functions
The Header Error Control (HEC) covers the entire cell header. The code used for this function is capable of either:

- single bit error correction, or

- multiple bit error detection.

Error detection shall be implemented as defined in ITU-T recommendation I.432 [3] with the exception that any HEC error may be considered as a multiple bit error, and therefore HEC error correction shall not be performed.

Header error control sequence generation.
The HEC byte shall be generated as described in ITU-T recommendation I.432 [3] including the recommended modulo 2 addition (XOR) of the pattern 01010101 to the HEC bits.

The generator polynomial coefficient set used and the HEC sequence generation procedure shall be in accordance with [3].

6.2.1.3) Idle cells.

Idle cells shall be inserted and discarded for cell rate decoupling. Idle cells are identified by the standardised pattern for the cell header given in [3].

The ATM layer may also perform cell rate decoupling by inserting and discarding unassigned cells. All implementations shall therefore be capable of receiving and discarding both idle cells (in the physical layer) and unassigned cells (in the ATM layer).

6.2.1.4) Cell delineation.

The cell delineation function permits the identification of cell boundaries in the payload. It u-ses the Header Error Control (HEC) field in the cell header.

Cell delineation shall be performed using the HEC based algorithm described in ITU-T re-commendation I.432 [3].

With reference to I.432 [3], The ADSL Forum makes no recommendation for the values of (and (as the choice of these values is not considered to effect interoperability. However, it should be noted that the use of the values suggested in I.432 could be inappropriate due to the particular transmission characteristics of ADSL

6.2.1.5) Cell payload scrambling.

Scrambling of the cell payload field shall be used to improve the security and robustness of the HEC cell delineation mechanism. In addition, it randomises the data in the information field, for possible improvement of the transmission performance. The self synchronising scrambler polynomial X43+1 and procedures defined in ITU-T recommendation I.432 [3] shall be implemented.

6.2.2) [B-NT1, B-NT, B-NT+TA or B-NT+TE] TC.

The functions of the TC block will be as those described in paragraph 6.2.1 for the access node.

6.3) [B-NT1, B-NT+TA or B-NT+TE] ATM and higher layer functions block.

If implemented, in the downstream direction this block combines the cell streams from the "Fast" and "Interleaved" buffers into a single ATM cell stream. In the upstream direction cell routing is performed on a VPI and/or VCI basis to the "Fast" or "Interleaved" TC sublayers.

7). Management.

7.1) General.

Non ATM specific OAM issues are for further study.

7.2) Network Management across the V interface.

For further study.

7.3) Operation, Administration and Maintenance (OAM).

7.3.1) Physical Layer OAM functions.

Modems compliant with ANSI T1.413 standard shall perform all OAM functions described in that standard.

Further OAM functions specific to ATM (described in ITU-T recommendations I.432 [3] and I.610 [4]) will be performed. LCD indication is derived from an HEC based cell delineation function. In particular, at the ATU-R the downstream LCD (Loss of Cell Delineation) defect (for the interleaved and fast path separately) shall be detected and backward reported to the ATU-C, via the indicator bits 14 and 15 in modems compliant to ANSI T1.413 standard, as shown in table 6.1 below.

The LCD-i (interleaved path) and LCD-ni (fast path) defects are mapped into the reserved indicator bits defined in [2] table 14, section 6.2.1.1, according to the following:

Bit 14	Bit 15	Interpretation
1	1	notLCD-i and notLCD-ni
1	0	notLCD-i and LCD-ni
0	1	LCD-i and notLCD-ni
0	0	LCD-i and LCD-ni

Table 6.1

8). References.

[1] ADSL Forum Reference model, TR-001.
[2] ANS, Network and Customer Installation Interfaces - Asymmetric Digital Subscriber Line (ADSL) Metallic interface, T1.413-1995.
[3] ITU-T Recommendation I.432 - B-ISDN UNI Physical Layer Specification, March 1993.
[4] ITU-T Recommendation I.610 - B-ISDN Operation and Maintenance Principles and Functions, March 93.
[5] ITU-T recommendation I.321 - B-ISDN Protocol Reference Model and its Application.
[6] ITU-T recommendation I.361 - B-ISDN ATM Layer specification, March 93.

[7] ETSI Technical Report, ETR 328 Transmission and Multiplexing – ADSL Requirements and Peformance.
[8] ATM Forum af-phy-0040.000, "Physical Interface Specification for 25.6 Mbit/s over Twisted Pair Cable", November 1995.
[9] ITU-T Recommendation I.413 - B-ISDN User-Network Interface.

ANNEX A: Glossary

Access Node:
Performs adaptation between the core network and the access network ADSL:
Asymmetric Digital Subscriber Line

ANSI:
American National Standard Institution

ASO-3:
Downstream simplex sub-channel designators

ATM:
Asynchronous Transfer Mode

ATU-C:
ADSL Transceiver Unit, central office end

ATU-R:
ADSL Transceiver Unit, remote terminal end

BER:
Bit Error Ratio

B-ISDN:
Broadband ISDN (Broadband Integrated Services Digital Network).

DAVIC:
Digital Audio-Visual Council

ETSI:
European Telecommunications Standards Institute

FTTC:
Fiber to the Curb

FTTH:
Fiber to the Home

HAN
Home ATM Network

HEC:

ATM cell Header Error Control.

HFC:
Hybrid Fiber Coaxial

ISDN:
Integrated Services Digital Network

ITU-T:
International Telecommunications Union - Telecommunications

LCD:
Loss of Cell Delineation

LSO-3:
Duplex sub-channel designators

NT:
Network Termination

B-NT1:
B-ISDN Network Termination Type 1.

OAM:
Operation, Administration and Maintenance.

PC:
Personal Computer

PDN:
Premises Distribution Network. System for connecting the B-NT1 to the Service Modules.

PHY:
ATM Physical layer function.

PMD:
ATM Physical Medium Dependent sublayer.

QoS:
Quality of Service

RBB:
(ATM Forum) Residential Broadband (Working Group)

SM:
Service Module; performs terminal adaptation functions.

STB:
Set-Top-Box

TA:

Terminal Adapter

TC:
ATM Transmission Convergence sublayer.

TE:
Terminal Equipment

UNI:
User-Network Interface

Va:
Logical interface between ATU-C and Access Node.

Vc:
Interface between Access Node and network.

VDSL:
Very high speed Digital Subscriber Line

VPI:
Virtual Path Identifier. Identification number for the (logical) connection hierarchy "path" (virtual path) in B-ISDN networks.

VCI:
Virtual Channel Identifier. Identification number for the (logical) connection hierarchy "channel" (virtual channel) in B-ISDN networks.

Annex B: Relationship to Other Reference Models.

B.1 ATM Forum

ATM Forum Residential Broadband (RBB) Group is defining a complete end to end ATM system both to and from the home and within the home, to a variety of devices, e.g., STB, PC, and other home devices. The ATM Forum RBB group has produced a baseline text.

ADSL, together with other technologies such as HFC, FTTC, FTTH, and VDSL, has been accepted as one of the methods to connect an ATM access network to the Home ATM Network (HAN).

B.2) DAVIC

The pertinent parts of the DAVIC 1.0 specification [7] are the following:
- Part 2: System reference models and scenarios
- Part 4: Delivery system architectures and APIs
- Part 8: Lower layer protocols and physical interfaces

Part 4 of the DAVIC 1.0 specification [7] gives two options for the placement of the ADSL modem at the customer premises; inside the NT, resulting in an access network architecture with an Active NT; or located in the Set-Top-Box, resulting in an access network architecture with a Passive NT. The two architectures are depicted in figures B.1a and B.1b below.

Figure B.1a: DAVIC ADSL Access Network with active NT.

Figure B.1b: DAVIC ADSL Access Network with passive NT.

Comments

Annex C: Relevant Standards and Known Work in Other Standards Groups or Forums.

C.1) ANSI T1.413 1995

C.2) ETSI TM6

The ETSI Technical Report, ETR 328 Transmission and Multiplexing - ADSL Requirements and Performance, primarily covers performance issues related to particular European specific reference loops, noise models, and transport rate options. This document supersedes sections of ETR 328 with regard to transport rates and bearer channel allocations.

C.3) ATM Forum

Most of the work of ATM Forum concerning ADSL is done by the RBB Group.

In The ATM Forum ADSL is seen as one of the possible physical interfaces between the ATM access network and HAN. System aspects of ATM over ADSL are being addressed.

C.4) DAVIC

It is DAVIC's belief that "it would be very beneficial to both DAVIC and The ADSL Forum to exchange information and views about matters of common interest, to seek consensus and possibly to co-ordinate respective actions" (quoted from a recent letter from DAVIC's President to The ADSL Forum's President).

DAVIC's present status related to ADSL is:

DAVIC 1.2 Part 8 contains a section on "LONG RANGE BASEBAND ASYMMETRICAL PHY ON COPPER", pointing to The ADSL Forum WT-006-R7. This pointer was included after finalizing the Cell Specific TC Sublayer specification through an intense liaison with The ADSL Forum. DAVIC requested to be informed of further releases and/or updates of the "ATM over ADSL" Working Text.

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Glossary

(last update April 25, 1997)

Access Network That portion of a public switched network that connects access nodes to individual subscribers. The Access Network today is predominantly passive twisted pair copper wiring.

Access Nodes Points on the edge of the Access Network that concentrate individual access lines into a smaller number of feeder lines. Access Nodes may also perform various forms of protocol conversion. Typical Access Nodes are Digital Loop Carrier systems concentrating individual voice lines to T1 lines, cellular antenna sites, PBXs, and Optical Network Units (ONUs).

ADSL Asymmetric Digital Subscriber Line: Modems attached to twisted pair copper wiring that transmit from 1.5 Mbps to 9 Mbps downstream (to the subscriber) and from 16 kbps to 800 kbps upstream, depending on line distance.

APON ATM Passive Optical Network: a passive optical network running ATM.

ATM Asynchronous Transfer Mode: an ultra high speed cell based data transmission protocol which may be run over ADSL.

ATM25 ATM Forum defined 25.6Mbit/s cell based user interface based on IBM token ring network.

ATU-C and ATU-R ADSL Transmission Unit, Central or Remote: the device at the end of an ADSL line that stands between the line and the first item of equipment in the subscriber premises or telephone switch. It may be integrated within an access node.

BDSL Same as VDSL.

B-ISDN Broadband Integrated Digital Network: A digital network with ATM switching operating at data rates in excess of 1.544 or 2.048 Mbps. ATM enables transport and switching of voice, data, image, and video over the same infrastructure.

CATV Community Access Television: also known as Cable TV.CPE Customer Premises Equipment: that portion of the ADSL system residing within the customer's premises.

Core Network Combination of switching offices and transmission plant connecting switching offices together. In the U.S. local exchange Core Networks are linked by several competing Interexchange networks; in the rest of the world (now) the Core Network extends to national boundaries.

CSA Carrier Serving Area: area served by a LEC, RBOC or telco, often using Digital Loop Carrier (DLC) technology.

DSLAM Digital Subscriber Line Access Multiplexer: specifically, a device which takes a number of ADSL subscriber lines and concentrates these to a single ATM line

DS0 Digital Signal 0: 64 kbps digital representation of voice.

DS1 Digital Signal 1: Twenty four voice channels packed into a 193 bit frame and transmitted at 1.544 Mbps. The unframed version, or payload, is 192 bits at a rate of 1.536 Mbps.

DS2 Digital Signal 2: Four T1 frames packed into a higher level frame transmitted at 6.312 Mbps.

DSL Digital Subscriber Line: Modems on either end of a single twisted pair wire that delivers ISDN Basic Rate Access.

E1 European basic multiplex rate which packs thirty voice channels into a 256 bit frame and transmitted at 2.048 Mbps.

Feeder Network That part of a public switched network which connects access nodes to the core network.

FEXT Far End CrossTalk: the interference occurring between two signals at the end of the lines remote from the telphone switch.

FTTCab Fibre To The Cabinet: network architecture where an optical fiber connects the telephone switch to a street-side cabinet where the signal is converted to feed the subscriber over a twisted copper pair.

TTH Fibre To The Home: network where an optical fibre runs from telephone switch to the subscriber's premises or home.

FTTK or FTTC Fiber To the Kerb: a network where an optical fiber runs from telephone switch to a kerbside distribution point close to the subscriber where it is converted to a copper pair.

HFC Hybrid Fibre Coax: a system (usually CATV) where fibre is run to a distribution point close to the subscriber and then the signal is converted to run to the subscriber's premises over coaxial cable.

HDSL High data rate Digital Subscribe Line: Modems on either end of one or more twisted pair wires that deliver T1 or E1 speeds. At present T1 requires two lines and E1 requires three. See SDSL for one line HDSL.

ISDL Uses ISDN transmission technology to deliver data at 128kbps into an IDSL "modem bank" connected to a router.

ISP Internet Service Provider: an organization offering and providing Internet services to the public and having its own computer servers to provide the services offered.

AN Local Area Network.

LEC Local Exchange Carrier: one of the new U.S. telephone access and service providers that have grown up with the recent U.S. deregulation of telecommunications.

MPEG Motion Picture Experts Group: the group that has defined the standards for compressed video transmission.

NAP Network Access Provider: another name for the provider of networked telephone and associated services, usually in the U.S.

NEXT Near End CrossTalk: the interference between pairs of lines at the telephone switch end.

N-ISDN Narrowband ISDN: same as ISDN

NSP Network Service Provider: the term for an organization offering and providing value added network services on a telecommunications network.

NTE Network Termination Equipment: the equipment at the ends of the line.

OC3 Optical Carrier 3: an optical fibre line carrying 155mbps; a U.S. designation generally recognized throughout the telecommunications community worldwide.

ONU Optical Network Unit: A form of Access Node that converts optical signals transmitted via fiber to electrical signals that can be transmitted via coaxial cable or twisted pair copper wiring to individual subscribers.

PON Passive Optical Network: the usual acronym for a fibre based transmission network containing no active electronics.

POTS Plain Old Telephone Service: the only name recognized around the world for basic analog telephone service. POTS takes the lowest 4kHz of bandwidth on twisted pair wiring. Any service sharing a line with POTS must either use frequencies a bove POTS or convert POTS to digital and interleave with other data signals.

PTT The generic European name usually used to refer to state owned telephone companies.

RADSL Rate Adaptive ADSL: a version of ADSL where the modems test the line at start up and adapt their operating speed to the fastest the line can handle.

RBOC Regional Bell Operating Company: one of the seven U.S. Telephone companies that resulted from the break up of AT&T.

SDSL Symmetric Digital Subscriber Line: HDSL plus POTS over a single telephone line. This name has not been adopted by a standards group, but is being discussed by ETSI. It is important to distinguish, however, as SDSL operates over POTS and would be suitable for symmetric services to premises of individual customers.

STS-1 SONET basic transmission rate of 51.84 Mbps.

T1 Same as DS1.

Telco The generic name for telephone companies throughout the world which encompasses RBOCs, LECs and PTTs.

TPON Telephony over Passive Optical Network: telephony using a PON as all or part of the transmission system between telephone switch and subscriber.

UDSL Unidirectional HDSL as proposed by one company in Europe without much sign of interest from anyone else.

VADSL Very high speed ADSL: same as VDSL (or a subset of VDSL, if VDSL includes symmetric mode transmission)

VDSL Very high data rate Digital Subscriber Line: Modem for twisted-pair access operating at data rates from 12.9 to 52.8 Mbps with corresponding maximum reach ranging from 4500 feet to 1000 feet of 24 gauge twisted pair.

WAN Wide Area Network: Private network facilities, usually offered by public telephone companies but increasingly available from alternative access providers (sometimes called Competitive Access Providers, or CAPs), that link business network nodes.

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TECHNICAL REPORT

ADSLForumTR-001

ADSL Forum System Reference Model

Contents

Abstract

This technical report presents an ADSL-based System Reference Model and defines all rela-vent interfaces present in an ADSL Access Network.

1.0 Overall Network and ADSL

The ADSL Forum develops technical guidelines for architectures, interfaces, and protocols for telecommunications networks incorporating ADSL transceivers. The overall network diagram below describes the network elements incorporated in multimedia communications, shows the scope of the Forum's work, and suggests a group of transport configurations ADSL will encounter as networks migrate from Synchronous Transfer Mode (STM) to Asynchronous Transfer Mode (ATM).

ADSL Asymmetric Digital Subscriber Line
ATM Asynchronous Transfer Mode
OS Operations System
PDN Premises Distribution Network
SM Service Module
STM Synchronous Transfer Mode
TE Terminal Equipment
See System Reference Model for reference point definitions

2.0 System Reference Model

Definitions

ATU-C: ADSL Transmission Unit at the network end. The ATU-C may be integrated within an Access Node.

ATU-R: ADSL transmission Unit at the customer premises end. The ATU-R may be integrated within an SM.

Access Node: Concentration point for Broadband and Narrowband data. The Access Node may be located at a Central Office or a remote site. Also, a remote Access Node may subtend from a central access node.

B: Auxiliary data input (such as a satellite feed) to Service Module (such as a Set Top Box).

Broadcast: Broadband data input in simplex mode (typically broadcast video).

Broadband Network: Switching system for data rates above 1.5/2.0 Mbps.

Loop: Twisted-pair copper telephone line. Loops may differ in distance, diameter, age, and transmission characteristics depending on network.

Narrowband Network: Switching system for data rates at or below 1.5/2.0 Mbps.

POTS: Plain Old Telephone Service.

POTS-C: Interface between PSTN and POTS splitter at network end.

POTS-R: Interface between phones and POTS splitter at premises end.

PDN: Premises Distribution Network: System for connecting ATU-R to Service Modules. May be point-to-point or multipoint; may be passive wiring or an active network. Multipoint may be a bus or star.

PSTN: Public Switched Telephone Network.

SM: Service Module: Performs terminal adaption functions. Examples are set top boxes, PC interfaces, or LAN router.

Splitter: Filters which separate high frequency (ADSL) and low frequency (POTS) signals at network end and premises end. The splitter may be integrated into the ATU, physically separated from the ATU, or divided between high pass and low pass, with the low pass function physically separated from the ATU. The provision of POTS splitters and POTS-related functions is optional.

T-SM: Interface between ATU-R and Premises Distribution Network. May be same as T when network is point-to-point passive wiring. An ATU-R may have more than one type of T-SM interface implemented (e.g., a T1/E1 connection and an Ethernet connection). The T-SM interface may be integrated within a Service Module.

T: Interface between Premises Distribution Network and Service Modules. May be same as T-SM when network is point-to-point passive wiring. Note that T interface may disappear at the physical level when ATU-R is integrated within a Service Module.

U-C: Interface between Loop and POTS Splitter on the network side. Defining both ends of the Loop interface separately arises because of the asymmetry of the signals on the line.

U-C2: Interface between POTS splitter and ATU-C. Note that at present ANSI T1.413 does not define such an interface and separating the POTS splitter from the ATU-C presents some technical difficulties in standardizing the interface.

U-R: Interface between Loop and POTS Splitter on the premises side.

U-R2: Interface between POTS splitter and ATU-R. Note that at present ANSI T1.413 does not define such an interface and separating the POTS splitter from the ATU-R presents some technical difficulties in standardizing the interface.

VA: Logical interface between ATU-C and Access Node. As this interface will often be within circuits on a common board, the ADSL Forum does not consider physical VA interfaces. The V interface may contain STM, ATM, or both transfer modes. In the primitive case of point-to-point connection between a switch port and an ATU-C (that is, a case without concentration or multiplexing), then the VA and VC interfaces become identical (alternatively, the VA interface disappears).

VC: Interface between Access Node and network. May have multiple physical connections (as shown) although may also carry all signals across a single physical connection. A digital carrier facility (e.g., a SONET or SDH extension) may be interposed at the VC interface when the access node and ATU-Cs are located at a remote site. Interface to the PSTN may be a universal tip-ring interface or a multiplexed telephony interface such as specified in Bellcore TR-08 or TR-303. The broadband segment of the VC interface may be STM switching, ATM switching, or private line type connections.

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ADSL Tutorial

Twisted Pair Access to the Information Highway

Asymmetric Digital Subscriber Line (ADSL), a new modem technology, converts existing twisted-pair telephone lines into access paths for multimedia and high speed data communications. ADSL transmits more than 6 Mbps (optionally up to 8 Mbps) to a subscriber, and as much as 640 kbps (optionally up to 1 Mbps) more in both directions. Such rates expand existing access capacity by a factor of 50 or more without new cabling. ADSL can literally transform the existing public information network from one limited to voice, text and low resolution graphics to a powerful, ubiquitous system capable of bringing multimedia, including full motion video, to everyone's home this century.

ADSL will play a crucial role over the next ten or more years as telephone companies enter new markets for delivering information in video and multimedia formats. New broadband cabling will take decades to reach all prospective subscribers. But success of these new services will depend upon reaching as many subscribers as possible during the first few years. By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses, ADSL will make these markets viable, and profitable, for telephone companies and application suppliers alike.

Capabilities

An ADSL circuit connects an ADSL modem on each end of a twisted-pair telephone line, creating three information channels -- a high speed downstream channel, a medium speed duplex channel, depending on the implementation of the ADSL architecture, and a POTS (Plain Old Telephone Service) or an ISDN channel. The POTS/ISDN channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS/ISDN, even if ADSL fails. The high speed channel ranges from 1.5 to 6.1 Mbps, while duplex rates range from 16 to 640 kbps. Each channel can be submultiplexed to form multiple, lower rate channels, depending on the system.

ADSL modems provide data rates consistent with North American and European digital hierarchies and can be purchased with various speed ranges and capabilities. The minimum configuration provides 1.5 or 2.0 Mbps downstream and a 16 kbps duplex channel; others provide rates of 6.1 Mbps and 64 kbps duplex. Products with downstream rates up to 8 Mbps and duplex rates up to 640 kbps are available today. ADSL modems will accommodate ATM transport with variable rates and compensation for ATM overhead, as well as IP protocols.

Downstream data rates depend on a number of factors, including the length of the copper line, its wire gauge, presence of bridged taps, and cross-coupled interference. Line attenuation increases with line length and frequency, and decreases as wire diameter increases. Ignoring bridged taps, ADSL will perform as follows:

Data Rate	Wire Gauge	Distance	Wire Size	Distance
1.5 or 2 Mbps	24 AWG	18,000 ft	0.5 mm	5.5 km
1.5 or 2 Mbps	26 AWG	15,000 ft	0.4 mm	4.6 km
6.1 Mbps	24 AWG	12,000 ft	0.5 mm	3.7 km
6.1 Mbps	26 AWG	9,000 ft	0.4 mm	2.7 km

While the measure varies from telco to telco, these capabilities can cover up to 95% of a loop plant depending on the desired data rate. Customers beyond these distances can be reached with fiber-based digital loop carrier systems. As these DLC systems become commercially available, telephone companies can offer virtually ubiquitous access in a relatively short time.

Many applications envisioned for ADSL involve digital compressed video. As a real time signal, digital video cannot use link or network level error control procedures commonly found in data communications systems. ADSL modems therefore incorporate forward error correction that dramatically reduces errors caused by impulse noise. Error correction on a symbol by symbol basis also reduces errors caused by continuous noise coupled into a line.

Technology

ADSL depends upon advanced digital signal processing and creative algorithms to squeeze so much information through twisted-pair telephone lines. In addition, many advances have been required in transformers, analog filters, and A/D converters. Long telephone lines may attenuate signals at one megahertz (the outer edge of the band used by ADSL) by as much as 90 dB, forcing analog sections of ADSL modems to work very hard to realize large dynamic ranges, separate channels, and maintain low noise figures. On the outside, ADSL looks simple -- transparent synchronous data pipes at various data rates over ordinary telephone lines. On the inside, where all the transistors work, there is a miracle of modern technology.

To create multiple channels, ADSL modems divide the available bandwidth of a telephone line in one of two ways -- Frequency Division Multiplexing (FDM) or Echo Cancellation. FDM assigns one band for upstream data and another band for downstream data. The downstream path is then divided by time division multiplexing into one or more high speed channels and one or more low speed channels. The upstream path is also multiplexed into corresponding low speed channels. Echo Cancellation assigns the upstream band to over-lap the downstream, and separates the two by means of local echo cancellation, a technique well know in V.32 and V.34 modems. With either technique, ADSL splits off a 4 kHz region for POTS at the DC end of the band.

An ADSL modem organizes the aggregate data stream created by multiplexing downstream channels, duplex channels, and maintenance channels together into blocks, and attaches an error correction code to each block. The receiver then corrects errors that occur during transmission up to the limits implied by the code and the block length. The unit may, at the users option, also create superblocks by interleaving data within subblocks; this allows the receiver to correct any combination of errors within a specific span of bits. This allows for effective transmission of both data and video signals alike.

Standards and Associations

The American National Standards Institute (ANSI), working group T1E1.4, recently approved an ADSL standard at rates up to 6.1 Mbps (ANSI Standard T1.413). The European Technical Standards Institute (ETSI) contributed an Annex to T1.413 to reflect European requirements. T1.413 currently embodies a single terminal interface at the premise end. Issue II will expand the standard to include a multiplexed interface at the premise end, protocols for configuration and network management, and other improvements.

The ATM Forum and DAVIC have both recognized ADSL as a physical layer transmission protocol for unshielded twisted pair media.

The ADSL Forum was formed in December of 1994 to promote the ADSL concept and facilitate development of ADSL system architectures, protocols, and interfaces for major ADSL applications. The Forum has approximately 300 members representing service providers, equipment manufacturers, and semiconductor companies from throughout the world.

Market Status

ADSL modems have been tested successfully in more than 100 telephone companies, telecom operators, and thousands of lines have been installed in various technology trials in North America, Europe and Asia. Several telephone companies plan market trials using ADSL, principally for data access, but also including video applications for such applications as personal shopping, interactive games, and educational programming.

Semiconductor companies have introduced transceiver chipsets that are already being used in
market trials. These chipsets combine off the shelf components, programmable digital signal processors and custom ASICS. Continued investment by these semiconductor companies have increased functionality and reduce chip count, power consumption, and cost, enabling mass deployment of ADSL-based services.

NOTE: The ADSL Forum takes no position on particular implementations of ADSL, or specific vendor features, pricing, or performance. This monograph therefore omits any discussion of line code (the basic modulation system) or the various trade-offs between performance and costs. The Forum does maintain a roster of vendors who can address these areas. For further information send a message to ADSLForum@adsl.com.