Go Back

What is ADSL ???

Tutorial FAQ Glossary General Introduction to Copper Access Technologies

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 to a subscriber, and as much as 640 kbps 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, and a POTS (Plain Old Telephone Service) channel. The POTS channel is split off from the digital modem by filters, thus guaranteeing uninterrupted POTS, 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.

ADSL modems provide data rates consistent with North American and European digital hierarchies (see Table 1) 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, now under study by T1E1.4, 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 more than 200 members representing service providers, equipment manufacturers, and semiconductor companies from throughout the world.

Market Status

ADSL modems have been tested successfully in more than 30 telephone companies, and thousands of lines have been installed in various technology trials in North America and Europe. 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.

Frequently Asked Questions

What does ADSL stand for?

> Asymmetric Digital Subscriber Line. The name was coined by Bellcore in 1989, and refers to the two way capability of a twisted copper pair with analog to digital conversion at the subscriber end and an advanced transmission technology.

What is ADSL anyway?

> ADSL is the use of the frequency spectrum between 0khz and 4khz for POTS and 4khz to 2.2mhz for data over a twisted-pair copper line, usually a telephone line. This line then provides asymmetric transmission of data, up to 9 Mbps downstream (to the customer) and up to 800 kbps upstream, depending upon line length and line and loop conditions.

What is the market for ADSL?

> ADSL can provide asymmetrical megabit access for two general types of applications -- interactive video and high speed data communications. Interactive video includes movies on demand, other video on demand such as delayed TV segments, video games, video catalogs, and video information retrieval. Data communications covers Internet access, telecommuting (remote LAN access), and specialized network access. While interactive video was the initial market stimulus for ADSL, recent excitement has centered on Internet and telecommuting applications particularly for SOHO (Small Office/Home Office) applications. The strength of ADSL compared to other high speed transmission alternatives (such as cable modems or Fiber To The Neighborhood (FTTN) lies in the number of existing telephone lines -- now approaching 700 million -- compared to new cabling which has reached comparatively few homes and no small businesses.

When is the market for ADSL?

ADSL is still in the market trial stage with telephone companies around the globe. Many telephone companies have expressed the intention of offering ADSL services for Internet access and other packet-based communications applications in 1997. In some countries, such as Australia, ADSL will be used for interactive and broadcast video in 1997. Two publicly available services are already in operation, one in Chicago, USA and one in Saskatchewan, CANADA.

How big will the ADSL market be?

The ADSL Forum does not project market size. The Forum does give some information about telephone lines, personal computers, and other market ingredients based on known data today. Several Essays on the Forum's Editorial Page make some predictions about the market, but they have not been, and will not be, endorsed by the Forum itself.

The group of U.S. telcos, known collectively as the Joint Procurement Consortium (Ameritech, Bell South, Pacific Bell, and Southwestern Bell), representing over 45% of the U.S. copper line market, has endorsed ADSL and is moving forward with market trials in 1997; the Consortium plans to deploy more than 2 million ADSL lines over the next 5 years.

Can I get ADSL today?

You could buy a modem, but it wouldn't do you much good unless you had your own lines. ADSL is still in the trial stage with telephone companies around the globe. Many telephone companies have expressed the intention of offering ADSL services for Internet access and other packet-based communications in 1997. However, early tariff services will only be available selectively for the first year or two of service offering, as telephone companies equip central offices with access network hardware.

How will telephone companies tariff ADSL?

The ADSL Forum can only speculate on this matter, and as a matter of policy, will not do so. However, preliminary announcements from some telephone companies suggest that they intend to be competitive with Cable Modem pricing.

What will ADSL do to ISDN?

That all depends upon the telephone companies offering both services. The two services are not the same -- ISDN provides two voice channels or a 128kbps data channel while ADSL is predominantly a data pipe providing an asymmetrical bandwidth of up to 9mbps downstream and 800 kbps upstream. However, an ADSL access network will be an overlay network and therefore not require the expensive and time-consuming switch upgrades that held ISDN back for so long. ADSL is a separate network, and will be available rapidly as soon as the protocols and kinks are worked out (sometime in 1997). If ADSL tariffs resemble ISDN tariffs, then one would expect ADSL to be favored for Internet and video applications.

Can the Internet keep up with so much speed?

Today, probably not. Many servers operate at 56 kpbs, the backbone has grown in an unplanned fashion and a connection may see 20 or more routers, creating significant delay, and for TCP connections, bandwidth throttling. However, a great deal of work is underway to (1) increase server access speeds, (2) improve backbone and NAP bandwidth, (3) increase router speeds, and (4) introduce ATM into the backbone for much lower latency. Futhermore, many Internet Service Providers will implement proxy or cache servers for frequently visited web pages, creating local access at least for these pages. By the time ADSL is widely available (probably in 1998), the Internet should have enough capacity to handle it. Even if it doesn't, ADSL will make many Internet experiences much better than voice band modems and the resulting market pressures will inevitably lead to capacity increases.

How does ADSL compare to Cable Modems?

ADSL provides a dedicated service over a single telephone line; cable modems offer a dedicated service over a shared media. While cable modems have greater downstream bandwidth (up to 30 Mbps), that bandwidth is shared among all users on a line, and will therefore vary, perhaps dramatically, with traffic. Cable modem upstream traffic will in many cases be slower than ADSL, either because the particular cable modem is inherently slower, or becasue of rate reductions caused by contention for upstream bandwidth slots. The big difference between ADSL and Cable Modems, however, is the number of lines available to each. There are no more than 12 million homes passed today that can support cable modems, and while the figure also grows steadily, it will not catch up with telephone lines for many years. Additionally, many of the older cable networks are not capable of offering a return channel; consequently, such networks will need significant upgrading before they can offer high bandwidth services.

What is the controversy between CAP and DMT?

CAP and DMT are two "line codes" or modulation systems currently on the market today for ADSL. The Forum has taken no position on the merits or demerits of either. Each line code has its own case, which should be got from the supporters directly. All major ADSL vendors belong to The ADSL Forum, and work together to create system guidelines and market positions independent of line code. As such, it can be fairly represented that the line code issue will have little bearing on the size, speed, or character of the ADSL market as a whole.

What is CAP?

CAP stands for Carrier-less Amplitude/Phase modulation, and describes a version of QAM in which incoming data modulates a single carrier that is then transmitted down a telephone line. The carrier itself is suppressed before transmission (it contains no information, and can be reconstructed at the receiver), hence the adjective "carrier-less."

What is DMT?

DMT stands for Discrete Multi-Tone, and describes a version of multicarrier modulation in which incoming data is collected and then distributed over a large number of small individual carriers, each of which uses a form of QAM modulation. DMT creates these channels using a digitial technique known as Discrete Fast-Fourier Transform. DMT is the basis of ANSI Standard T1.413.

What is DWMT?

DWMT stands for Discrete Wavelet Multi-Tone, and describes a version of multicarrier modulation in which each carrier is created by Wavelet transform rather than Fourier

Transform.

What is xDSL?

XDSL is the name which as been coined for the family of DSLs ranging from HDSL through to VDSL (see accompanying Glossary with ADSL firmly in the middle of the speed/capacity band.

How can I find out when I can have ADSL?

The ADSL Forum is not in a position to provide information about the plans of individual NAPs or telcos. You should telephone your local telephone service provider to ask them when they will make such services available. Also, you may fill in the Forum's questionnaire; the responses are reqularly compiled and passed, in an unidentifiable form, to telcos to provide them with an indication of the rapidly growing demand for ADSL.

What Does ADSL Offer the Internet Service Provider?

Today, high speed Internet access is seen by many as the first "killer" application of ADSL - there is a pent up demand for higher access speeds and only ADSL can practically provide these speeds. Today's analog modems routinely offer 28.8kbps or 33.6kbps and, in a few but growing number of instances, up to 56kbps. However, 56kbps is probably the practical limit for analog modems. ISDN can increase this to 128kbps but this is still slow compared to ADSL speeds of between 1.5mbps and 9.0mbps. ADSL will open a whole new world of virtually instantaneous downloading of massive graphics and even a form of video over the Internet.

Glossary

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.

FTTH 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.

LAN 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.

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[3]	Data communications

DSL	Digital Subscriber Line	160 kbps[2]	Duplex	ISDN service Voice and data comm
HDSL[6]	High data rate Digital Subscriber Line	1.544 Mbps[4] 2.048 Mbps[5]	Duplex Duplex	T1/E1 service Feeder plant, WAN, LAN access, server access
SDSL	Single line Digital Subscriber Line	1.544 Mpbs 2.048 Mbps	Duplex Duplex	Same as HDSL plus premises access for symmetric services
ADSL	Asymmetric Digital Subscriber Line	1.5 to 9 Mbps 16 to 640 kbps	Down[8] Up	Internet access, video on demand, simplex video, remote LAN access, interactive multimedia
VDSL[7]	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. 192 Kbps divides into two B channels (64 kbps), one D channel (16 kbps) and link administration.
3. "Duplex" means data of the same rate both upstream and downstream at the same time.
4. Requires two twisted-pair lines
5. Requires three twisted-pair lines
6. A new system called SDSL, for Single Line DSL, operates at 1.5 or 2.0 Mbps duplex over one line
7. Also called BDSL, VADSL, or, at times, ADSL. VDSL is ANSI and ETSI designation.
8. "Down" means downstream, from the network to the subscriber. "Up" means upstream.
9. Future VDSL systems may have upstream rates equal to downstream, but on much shorter lines.

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 European 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.

---

to the top