AG Communication Systems

Asymmetric Digital Subscriber Line (ADSL)

Definition

Asymmetric digital subscriber line (ADSL) is a new modem technology that converts existing twisted-pair telephone lines into access paths for high-speed communications of various sorts.

Overview

ADSL can transmit more than 6 Mbps to a subscriber—enough to provide Internet access, video-on-demand, and LAN access. In interactive mode it can transmit more than 640 kbps in both directions. This increases the existing access capacity by more than fifty-fold enabling the transformation of the existing public network. No longer is it limited to voice, text, and low-resolution graphics. It promises to be nothing less than an ubiquitous system that can provide multimedia (including full-motion video) to the entire country. ADSL can perform as indicated in *Table 1*.

Table 1. ADSL Data Rates As a Function of Wire and Distance

Data Rate (Mbps)	Wire Gauge (AWG)	Distance (ft)	Wire Size (mm)	Distance (km)
1.5–2.0	24	18,000	0.5	5.5
1.5–2.0	26	15,000	0.4	4.6
6.1	24	12,000	0.5	3.7
6.1	26	9,000	0.4	2.7

Topics

1. Short History of Analog Modems

1. A Short History of Analog Modems

The term modem is actually an acronym which stands for MOdulation/DEModulation. A modem enables two computers to communicate by using the public switched telephone network. This network can only carry sounds so modems need to translate the computer's digital information into a series of high-pitched sounds which can be transported over the phone lines. When the sounds arrive at their destination, they are demodulated—turned back into digital information for the receiving computer (see *Figure 1*).

Figure 1.

All modems use some form of compression and error correction. Compression algorithims enable throughput to be enhanced two to four times over normal transmission. Error correction examines incoming data for integrity and requests retransmission of a packet when it detects a problem.

2. The Analog Modem Market

The dynamics of the analog-modem market can be traced back to July 1968 when, in its landmark Carterfone decision, the FCC ruled that "the provisions prohibiting the use of customer-provided interconnecting devices were unreasonable."

On January 1, 1969, AT&T revised its tariffs to permit the attachment of customer-provided devices (such as modems) to the public switched network—subject to the following three important conditions:

- The customer-provided equipment was restricted to certain output power and energy levels, so as not to interfere with or harm the telephone network in any way.

- The interconnection to the public switched network had to be made through a telephone company-provided protective device, sometimes referred to as a data access arrangement (DAA).

- All network-control signaling such as dialing, busy signals, and so on had to be performed with telephone-company equipment at the interconnection point.

By 1976, the FCC had recommended a plan whereby current protective devices would be phased out in favor of a so-called registration plan. Registration would permit direct switched-network electrical connection of equipment that had been inspected and registered by an independent agency such as the FCC as technically safe for use on the switched network.

In the post-war era, heavy emphasis on information theory led to the profound and now famous 1948 paper by Claude Shannon providing us with a concise understanding of channel capacity for power and bandlimited gaussian noise channels—our analog telephone channel.

$$C = Bw * Log2(1+S/N)$$

This simply states that the channel capacity, *C*, is equal to the available channel bandwidth, *Bw*, times the log base 2 of 1 plus the signal-to-noise ratio in that bandwidth. It does not explain "how" to accomplish this, it simply states that this channel capacity can be approached with suitable techniques.

As customers started buying and using modems, speed and reliability became important issues. Each vendor tried to get as close to the limit expressed by Shannon's Law as they could. Until Recommendation V.32, all modem standards seemed to fall short of this capacity by 9 to 10 db S/N. Estimates of the channel capacity used assumed bandwidths of 2400 Hz to 2800 Hz, and S/N ratios from 24 db to 30 db and generally arrived at a capacity of about 24,000 bits per second (bps). It was clear that error-correction techniques would have to become practical before this gap would be diminished.

Modems of the 1950's were all proprietary—primarily FSK (300 bps to 600 bps) and vestigial sideband (1200 bps to 2400 bps). These devices used or were built upon technology from RF radio techniques developed during the wartime era and applied to wireline communications.

International standardization of modems started in the 1960s. In the 1964 Plenary, the first CCITT Modem Recommendation, V.21 (1964), a 200 bps FSK modem (and now 300 bps) was ratified and is (still) used in the V.34/V.8 handshake. The preferred modulation progressed to 4 Phase (or 2X2 QAM) in 1968, and to 4X4 QAM with V.22bis in 1984. Additionally, in 1984, the next major technological advancement in modem recommendations came with V.32 and the addition of echo cancellation and trellis coding. Trellis codes, first identified by Dr. Gottfred Ungerboeck, were a major breakthrough in that they made it practical to provide a level of forward error correction to modems, realizing a coding gain of 3.5 db, and closing over a third of the "gap" in realizing the Shannon channel capacity. Recommendation V.32bis built on this and realized improvement in typical-connection S/N ratios and increased the data rates to 14,400 bps.

As work on V.34 started in earnest (1989/90), a recognition of further improvement in the telephone networks in many areas of the world was evident. With this recognition, the initial goal of 19,200 bps moved to 24,000 bps and then to 28,800 bps. The newer V.34 (1996) modem supports 33,600 bps. Such modems achieve 10 bits per Hertz of bandwidth, a figure which approaches the theoretical limits. Recently, a number of companies have introduced a 56.6-kbps analog modem designed to operate over standard phone lines. However, the modem is asymmetrical (it operates at normal modem speeds on the upstream end), it requires a dedicated T1/E1 connection to the ISP site to consistently reach its theoretical limits. For users without such a line the modem offers, inconsistently at best according to reports, a modest gain in performance.

However, the bandwidth limitations of voice band lines are not a function of the subscriber line but the core network. Filters at the edge of the core network limit voice-grade bandwidth to approximately 3.3 kHz. Without such filters, the copper access wires can pass frequencies into the MHz regions. Attenuation determines the data rate over twisted-pair wire, and it, in turn, is a function of line length and frequency. *Table 1* indicated the practical limits on data rates in one direction compared to line length.

3. Digital Subscriber Line (DSL)

Despite its name, DSL does not refer to a physical line but to a modem—or rather a pair of modems. A DSL modem pair creates a digital subscriber line, but the network does not purchase the lines when it buys ADSL—it already owns those—it purchases modems.

A DSL modem transmits duplex (i.e., data in both directions simultaneously) at 160 kbps over copper lines of up to 18,000 feet. DSL modems use twisted-pair bandwidth from 0 to approximately 80 kHz which precludes the simultaneous use of analog telephone service in most cases (see *Figure 2*).

Figure 2.

T1 and E1

In the early 1960s, Bell Labs engineers created a voice multiplexing system which digitized a voice sample into a 64 kbps data stream (8000 voltages samples per second) and organized these into a 24-element framed data stream with conventions for determining precisely where the 8-bit slots went at the receiving end. The frame was 193 bits long and created an equivalent data rate of 1.544 Mbps. The engineers called their data stream DS–1, but it has since come to be known as T1. Technically, though, T1 refers to the raw data rate, with DS–1 referring to the framed rate.

In Europe, the world's public telephone networks other than AT&T modified the Bell Lab approach and created E1—a multiplexing system for 30 voice channels running at 2.048 Mbps.

Unfortunately, T1/E1 is not really suitable for connection to individual residences. The transmission protocol they used, alternate mark inversion (AMI), required tranceivers 3,000 feet from the central office and every 6,000 feet thereafter. AMI demands so much bandwidth and corrupts the cable spectrum so much that telephone companies could use only one circuit in any 50-pair cable and none in any adjacent cables. Under these circumstances, providing high bandwidth service to homes would be equivalent to installing new wire.

4. xDSL

High Data-Rate Digital Subscriber Line (HDSL)

HDSL is simply a better way of transmitting T1/E1 over copper wires, using less bandwidth without repeaters. It uses more advanced modulation techniques to transmit 1.544 Mbps over lines up to 12,000 feet long.

Single-Line Digital Subscriber Line (SDSL)

SDSL is a single-line version of HDSL, transmitting T1/E1 signals over a single twisted pair, and able to operate over the plain old telephone service (POTS) so that a single line can support POTS and T1/E1 at the same time. It fits the market for residence connection which must often work over a single telephone line. However, SDSL will not reach much beyond 10,000 feet. At the same distance, ADSL reaches rates above 6 Mbps.

Asymmetric Digital Subscriber Line (ADSL)

ADSL is intended to complete the connection with the customer's premise. It transmits two separate data streams with much more bandwidth devoted to the downstream leg to the customer than returning. It is effective because symmetric signals in many pairs within a cable (as occurs in cables coming out of the central office) significantly limit the data rate and possible line length.

ADSL succeeds because it takes advantage of the fact that most of its target applications (video-on-demand, home shopping, Internet access, remote LAN access, multimedia, and PC services) function perfectly well with a relatively low upstream data rate. MPEG movies require 1.5 or 3.0 Mbps down stream but need only between 16 kbps and 64 kbps upstream. The protocols controlling Internet or LAN access require somewhat higher upstream rates but in most cases can get by with a 10 to 1 ratio of downstream to upstream bandwidth.

5. The Modem Market

Sales in the modem business started out slowly until customers started buying PCs. Likewise, costs were high until the volumes picked up. When the 14.4-kbps modem was first introduced, it cost $14,400—or one dollar per bit. Today, a much faster consumer-level modem with many more features costs only $100–$300, making it unusual for a home PC today to be without a modem.

Over the years, customers watched modem vendors evolve their products on a standards basis. This technique, although somewhat time consuming, was very important and led to significant feature enhancement. Initially, several modulation schemes were in use, but by the time the V.34 modem came out all of the major modem-modulation schemes were combined in that standard—giving the customer one modem that could be used in many applications. As the modem market matured, customers became less concerned with the internals of standards and more concerned with features, size, and flexibility.

As a result of the progress in analog-modem technology and with the advent of mass-market consumer-level PCs, there are over 500 million modems in the world today.

The xDSL modem market will follow similar market patterns. Today, things like modulation schemes, the type of protocol supported to the home or small business, and costs of the units are the main topics. As the xDSL market matures, most likely in a fashion similar to that of the analog modem, customers will become less concerned with modulation and protocols. On the other hand, they will look for vendors that provide plug-and-play interoperability with their data equipment, ease of installation, the best operating characteristics on marginal lines, and minimalist size and power requirements.

6. ATM versus IP to the Desktop

There is a great debate raging among potential service providers as to whether there should be standard IP–10BT connections or ATM connections to their customers' PCs. The two are very similar—the difference is in the specifics of the equipment and not in the amount of equipment required.

There are various advantages to each method of network access:

IP Advantages

- 10BT Ethernet is basically self-learning.
- Inexpensive LAN PC cards already exist.
- 10BT is an industry standard.
- LAN networks are proven and work today.
- There is much expertise in this technology.
- PC software and OS drivers already interface to IP–based LANs.

ATM Advantages

- Streaming video transport has already been proven.
- Mixing of services (e.g., video, telephony, and data) is much easier.
- Traffic speeds conform to standard telephony transport rates (e.g., DS–3, STS–1).
- New PC software and drivers will work with ATM.

The issue actually gets more interesting because both architectures usually interface to an ATM backbone network for high-speed connections over a wide area. Therefore, the real issues are the costs of building the network, the services that are to be carried over it, and the time frame for the implementation. If the need is for data services—Internet connections, work at home, etc., the obvious choice is an IP network. The hardware and software required to implement this network is available and relatively inexpensive.

ATM would be the solution for multiple mixed QoS service requirements in the near future. It is true that the IP technology is being extended to offer tiered QoS with RSVP, and IP telephony is being refined to operate more efficiently. The paradox, however, is that these standards do not exist today. ATM standards are quite complete. However, not all may be easily implementable. In spite of this, there are many ATM networks in existence or currently under construction.

This leaves the issue of costs. The true costs of creating and operating a large-scale data-access network are not known. True, there are portions that are understood, but many others are only projected. This creates great debate over which technology is actually less costly. The only way for the costs to be really known is to build reasonably large networks and compare costs. If one technology is a clear winner—a somewhat doubtful hypothesis—then use that technology. If there is no clear cost advantage, then build the network with the service set that matches the service needs of the potential customers. The issue is to start the implementation phase where the real answers will be determined and subsequently end the interminable discussion phase.

7. CAP versus DMT

These are the two primary xDSL standards over which much debate has ensued. Although the debate continues, the real action is taking place in the marketplace. CAP demonstrated a clear lead in getting product to market. Chips were available in quantity, and they worked. Numerous products that incorporated these chips are installed in a number of locations by service providers. Standards and interoperability issues between vendors and implementations are now being addressed.

DMT, on the other hand, has been in the standards arena for some time and continues to evolve. It is now considered a standard by a number of service providers. This technology featured some innovations that were not originally in the CAP feature set such as rate adaptation. On the other hand, the chips are just now finding their way into products. Trial activities are only now beginning, and advanced chip sets that match the features of CAP chips are now being promised for 3Q97.

The issue is which will win the market. The service providers who are building the xDSL network will select the technology that meets their needs. Many vendors are offering products that use either technology. Some new chips are being announced that allow adaptation between either technology. The point here is that the technology of xDSL chips is not a roadblock to deployment. Either appears to work well and true interoperability remains in the future much like mid-span meets for SONET equipment.

8. The Future

Look at the past of analog modems to foretell the future of xDSL. Standards were an issue with modems and will be an issue with xDSL products. However, it is not obvious to a technologist who or what technology will win out. Remember that in the VCR arena, Betamax had the better-quality picture, but VHS eventually won out. In any event, only the marketplace, and some time, will answer these questions.

Self-Test

1. ADSL increases existing twisted-pair access capacity by ______________.

    a. twofold

    b. threefold

    c. thirtyfold

    d. fiftyfold

2. A modem translates _________.

    a. analog signals into digital signals

    b. digital signals into analog signals

    c. both of the above

3. The 1948 theorem which is the basis for understanding the relationship of channel capacity, bandwidth, signal-to-noise ratio is known as _______.

    a. the Peter Principle

    b. the Heisenberg Uncertainty Principle

    c. Shannon's Law

    d. Boyle's Law

4. What appears to be the practical limit for analog modems over the standard telephone network?

    a. 33 kbps

    b. 28.8 kbps

    c. 24 kbps

    d. 19.2 kbps

5. Digital subscriber line (DSL) refers to _________.

    a. a specific gauge of wire used in modem communications

    b. a modem enabling high-speed communications

    c. a connection created by a modem pair enabling high-speed communications

    d. a specific length of wire

6. T1/E1 and HDSL are essentially equivalent technologies.

    a. true

    b. false

7. ADSL cannot handle Internet or LAN access.

    a. true

    b. false

8. What is the source of limitation on the bandwidth of the public switched network?

    a. subscriber line

    b. the core network

9. The practical upper limit of line length of ADSL is ___________.

    a. 6,000 ft

    b. 12,000 ft

    c. 18,000 ft

    d. 36,000 ft

10. T1 and DS–1 refer to the same multiplexing system. Which one is generally used to refer to the raw data rate?

    a. T1

    b. DS–1

Correct Answers

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    d. fiftyfold

    See Definition and Overview.

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    See Topic 2.

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    See Topic 3.

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    See Topic 3.

Acronym Guide

ADSL
asymmetric digital subscriber line

AMI
alternate mark inversion

ATM
asynchronous transfer mode

CAP
cellular array processor

DAA
data access arrangement

DMT
discrete multitone

DSL
digital subscriber line

FCC
Federal Communications Commission

HDSL
high data rate subscriber line

IP
Internet protocol

LAN
local area network

MPEG
Motion Pictures Expert Group

modem
modulation/demodulation

QoS
quality of service

SDSL
single line subscriber line

SONET
synchronous optical network