Introduction to Copper Access Technologies and ADSL

Distributed Multimedia Course Notes

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Introduction

With the advent of the Internet, more and more people want to connect their computers up to other computers. Also, the volumes of data that they want to send between these computers are growing, beyond the capabilities of the traditional analogue modem. To address this problem, the major telephone companies have proposed new methods for sending data quickly (and is large volumes) over copper cable. These new methods are loosely titled xDSL, where the x is replaced with a different letter to denote a different version of the product. For example, the first product was called HDSL (High data rate Digital Subscriber Line), followed closely by the main focus of this document, ADSL (Asymmetric Digital Subscriber Line), and then by an emerging technology VDSL (Very high data rate Digital Subscriber Line). The original research into what are now known as xDSL modems actually began long ago and these types of modems have been in use for many years as part of the core switching networks of many of the major world telcos. But, whereas before they were used to carry mainly voice type traffic, they are now being adapted to the needs of data traffic carriers. Table 1 lists the main forms of xDSL and the capabilities of each:

Name	Meaning	Data Rate	Mode	Applications
V.22, V.32, V. 34	Voice band modems	1200 BPS to 28,800 BPS	Duplex	Data Communications
DSL	Digital Subscriber Line	160 KBPS	Duplex	ISDN, voice and data services
HDSL	High data rate Digital Subscriber Line	1.544 MBPS 2.048 MBPS	Duplex	T1/E1 service, feeder plant, WAN/LAN access and server access
SDSL	Single line Digital Subscriber Line	1.544 MBPS 2.048 MBPS	Duplex	Same as HDSL, plus premises access for symmetric services
ADSL	Asymmetric Digital Subscriber Line	1.5 – 9 MBPS 16 – 640 KBPS	Down Up	Internet access, Video On Demand, simplex video, remote LAN access, interactive multimedia
VDSL	Very high data rate Digital Subscriber line	13 – 52 MBPS 1.5 – 2.3 MBPS	Down Up	Same as ADSL plus HDTV

Table 1 - Generic List of Copper Access Technologies

Introduction to Copper Wire Networks

The reason that xDSL technologies are able to provide a much better service than voice grade analogue modes is due mainly to the layout of the copper cable system. Voice grade modem operate over the normal telephone switching system, with signals travelling from the site of the sending node, into the core network of the telephone company, and from there, out again to the destination node, with the signals treated the same as normal voice signals. This is an advantage in that almost everywhere in the world is linked via the telephone system. However, the core network imposes certain bandwidth limitations on signals coming into it. For instance, there are filters at the edge of the core network that limit the incoming bandwidth to 3.3kHz, and without these filters, copper cables would be able to pass signals in the MHz regions, albeit with substantial attenuation. This attenuation, which increases with line length, is what limits the practical data rates over copper to those shown in table 2:

Access Type	Speed /MBPS	Usable Distance /km
DS1 (T1)	1.544	5.5
E1	2.048	5
DS2	6.312	3.5
E2	8.448	3
¼ STS-1	12.960	1.3
½ STS-1	25.920	0.9
STS-1	51.840	0.3

Table 2 - Practical Limits on Data Rate and Line Length

The average length of the subscriber loop varies tremendously depending on where in the world you are. In many countries, most (if not all) of the local loops are smaller than 5.5 km. In others, like the USA, 5.5 km only covers 80% of the people, with the other 20% or so having lines, which contain loading coils, making them useless for any form of xDSL technology, unless the loading coils are removed. There are moves underway in many countries to try and lower the length of the subscriber loop with projects such as the USA's 'fibre to the curb', where the idea is to lay fibre optic lines into a central point in every neighbourhood, from which the individual subscribers can be fed off with copper cable. This trend to shorten the length of the subscriber loop is going a long way to assist the introduction of copper access technologies, which typically only operate (at high data rates) for distances less than 6 km.

The History of the xDSL Modem

DSL or Digital Subscriber Line

Before going on, there is an important distinction that needs to be made between the name digital subscriber line, and what we are actually talking about when we say DSL. In general, DSL refers to the hardware on either end of the copper line, and not, as its name would suggest, to the actual line itself, which is plain old Unshielded Twisted Pair (UTP).

The original DSL was the modem used to implement Basic Rate ISDN. A generic DSL transmits data in both directions simultaneously i.e. full duplex, at 160 KBPS over copper lines up to 5.5 km of 24 (0.5-mm) gauge wire. The modems at either end break the bandwidth up into two B channels (64 KBPS each) and a D channel (16 KBPS). The original DSL modems used the bandwidth from 0 to about 80 kHz, and thus were not able to provide the simultaneous plain old telephone service that is a feature of xDSL modems i.e. the ability to use the copper line for both voice and data simultaneously and independently of each other.

While the specifications of the DSL modem may seem trivial by today's standards, at the time of their release they were fairly revolutionary and are, in fact, still in use today, mainly in what are termed pair-gain applications.

T1 and E1

The engineers at Bell labs created a multiplexing system, which send digitised voice through 24 framed 64 KBPS streams. The resulting frame was 193 bits long and created an equivalent data rate of 1.544 Mbps. This signalling method was named DS1, which was later expanded to T1 and includes different framing methods, etc. This was in wide use in the mid-1970's. In Europe, a modified T1 method was developed using 30 voice channels and giving an equivalent data rate of 2.048 Mbps. T1 and E1 circuits require a repeater 900 m from the node, and further repeaters for every 1800 m thereafter, making them expensive and maintenance intensive. Despite this, they were, and still are, widely implemented, although they are being phased out, and replaced with HDSL links.

HDSL (High data rate Digital Subscriber Line)

Simply put, HDSL is just a better way of transmitting T1 or E1 over twisted pair copper cables. Developed by Bellcore in the late 1980's, it uses less bandwidth than the traditional methods and operates without the need for costly repeaters. The idea behind HDSL was simply to develop a method of delivering a high-performance, cost-effective, 2 Mbps data stream over copper cables.

Initially, HDSL was used by Bellcore to provide T1/E1 links to remote areas, and later, HDSL was used for all new T1/E1 links. Today, HDSL is used mainly to provide advanced digital services to local loop customers and corporate end users. HDSL works by creating a mathematical model of the noise characteristics over the copper wire, allowing the transmitting device to precisely compensate for copper-based distortion. This adjustment occurs dynamically all the time, allowing the equipment to adjust to changes in the copper environment.

HDSL operates with a bandwidth of 1.544 Mbps up to 3.6 km on standard 24 gauge copper wire, and with certain enhancements or heavier gauge copper, up to 7 km. This was the first technology to provide fibre optic level network technologies over plain copper wires.

ADSL (Asymmetric Digital Subscriber Line)

An Introduction to ADSL

ADSL followed soon after the deployment of HDSL. ADSL is specifically tailored as a last leg link into customer premises. As its name suggests, the link provided by an ADSL modem is asymmetric i.e. it offers a single 6 Mbps link from the network to the subscriber, and a pair of 640 KBPS links, one from the subscriber to the network and the other from the network to the subscriber. The reasoning behind this asymmetric system is that the amount of information coming into the end users node is greater than the amount of information going out of the end users node, to the rest of the network. Studies on end user nodes running TCP/IP networking applications showed that the actual ratio of incoming to outgoing data, was often as high as 10:1!

Specifications of ADSL

An ADSL circuit is a point to point link connecting two nodes over a single twisted pair copper cable. This cable must be a dedicated line, and a normal telephone cable i.e. going through an exchange, will not suffice. ADSL provides a dedicated line type of connection. The ADSL modem creates three channels, a high speed downstream (from the end user node to the rest of the network) channel, a medium speed duplex channel and an ordinary telephone channel (see figure 1).

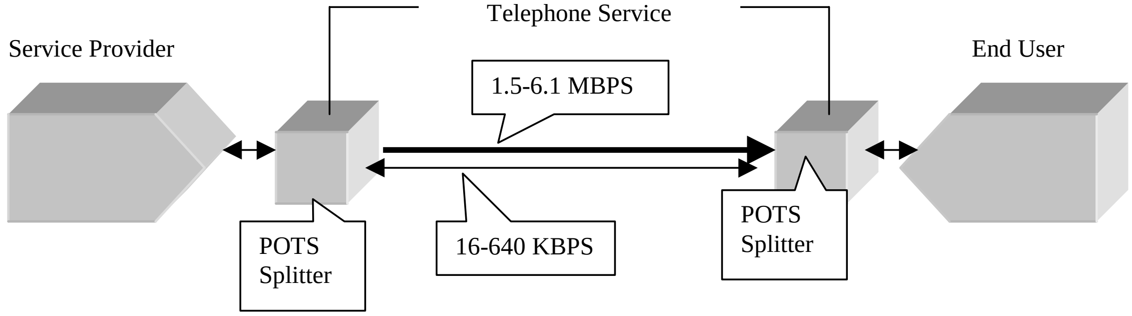

Figure 1 - Simple ADSL Schematic

The ordinary telephone channel (or Plain Old Telephone Service, POTS) is split off from the rest of the digital modem channels by means of filters in order to guarantee that, even if the modem should fail, the ordinary telephone service will be able to continue uninterrupted.

The actual bandwidth of the high-speed channel can range from 1.5 to 6.1 Mbps, while the duplex channel bandwidth ranges from 16 to 640 KBPS. Each of these channels can be submultiplexed to form several smaller channels if required.

The actual downstream data rate depends on a number of factors such as the length of the copper line, its wire gauge, the presence of bridged taps and cross-coupled interference. Ignoring the effects of bridged taps, an ADSL modem will perform as detailed in table 3.

ADSL employs forward error correction, which enables the receiving end to not only detect, but to correct errors in the transmitted data, thus dramatically reducing the effects of burst noise. The forward error correction was included to facilitate such real time applications as digital video. Error

Data Rate /MBPS	Wire Gauge /AWG	Wire Size /mm	Distance /km
1.5 or 2	24	0.5	5.5
1.5 or 2	26	0.4	4.6
6.1	24	0.5	3.7
6.1	26	0.4	2.7

Table 3 - ADSL Performance / Distance Table

correction on a symbol by symbol basis also reduces errors caused by continuous noise coupled into the line.

How ADSL Works

To the user, an ADSL modem looks deceptively simple - a 'black box' giving synchronous data pipes at various data rates, over ordinary telephone type copper lines. The actual inner working of the modem relies on sophisticated digital signal processing and a number of rather creative algorithms! Since copper cable lines tend to attenuate signals at 1 MHz (the outer edge of the ADSL band) by as much as 90dB, the analogue sections of the modem especially, have to work hard to maintain the large dynamic ranges, separate channels, and low noise figures, required to transmit such high bandwidths.

To provide the separate channels, the modem divides up the available bandwidth in one of two possible ways:

- *Frequency Division Multiplexing (FDM):* FDM works by assigning one band of frequency to the upstream data, and another separate band to the downstream data. The downstream path may then further subdivided, using Time Division Multiplexing (TDM) into one or more high-speed channels and a corresponding number of low speed channels, giving the *illusion* of multiple channels over a single connection. Likewise, the upstream path would also multiplexed into corresponding low speed channels. Figure 2 illustrates the FDM bandwidth.
- *Echo Cancellation:* Echo cancellation assigns the upstream band to overlap the downstream band, and separates the two using a method known as local echo cancellation, an established technique used in V.32 and V.34 analogue modems. Figure 3 illustrates echo cancellation bandwidth division.

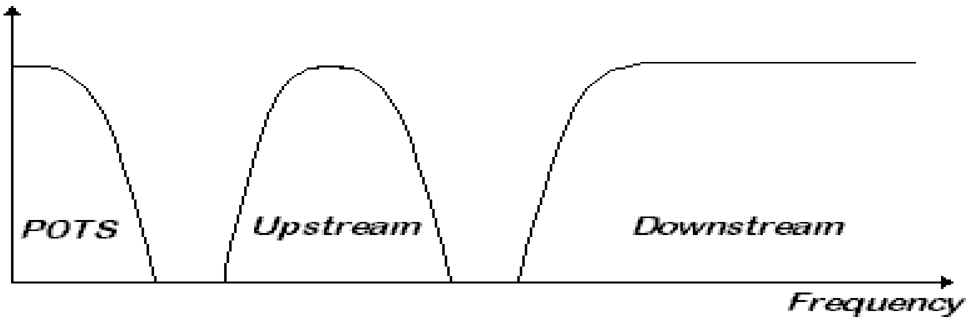

Figure 2 - FDM Bandwidth Division

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