DSL Modems

WHITE PAPER

DSL modems are devices that allow high-speed access to information at a distant server, which may be an Internet server, via the normal telephone network. Digital subscriber line (DSL) is a generic name for a family of standards that allow existing twisted pair copper lines (the phone wires) to carry modulated digital content at high speed by expanding the amount of frequency.

Despite its name, DSL does not refer to a physical line, but rather to a pair of modems that use encoding and multiplexing to create a line that is capable of transmitting both voice and data on the same line.

A DSL system comprises of DSL modem on the customer's end, commonly referred to as CPE (customer premise equipment), which is connected to another DSL Modem, DSLAM (DSL Access Multiplexer) at the Local Call office.

The paper further elaborates the following aspects of the DSL modem:
Working, standards, itu-t, dsl infrastructure, infrastructure requirement for cpe, infrastructure requirement for coe, variants of dsl modems, the simple dsl transceiver, the role of dslam, applications, dsl in education, voice over dsl.

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DSL Modems

DSL modems are devices that allow high-speed access to information at a distant server, which may be an Internet server, via the normal telephone network .

This may sound all too familiar and similar, to a dial up modem, which too operates via the existing telephone networks. The reader will discover the marked difference in the technol0gy and approach in the two techniques.

Overview

Digital Subscriber Line (DSL) is a generic name for a family of standards that allow existing twisted pair copper lines (the phone wires) to carry modulated digital content at high speed by expanding the mount of frequency used (which is available but unused by POTS).

Despite its name, DSL does not refer to a physical line, but rather to a pair of modems that use encoding and multiplexing to create a line that is capable of transmitting both voice and data on the same line.

The Technology

In the existing telephone networks, the carrier is commonly a 24-gauge twisted pair cable. The bandwidth carrying capacity of such ables is about 1 MHz.

All along these cables have only been used for the purpose of voice communication. The telephone is designed to transport analog signals, primarily Human voice. Normally, the range of signals required for this is from 300Hz to 3600 Hz, which means the bandwidth, is around 3,300Hz wide. In the dial up modems this limits the amount of “information” that can be transmitted . Wasting about **99.7%** of the bandwidth.

The DSL technology breaks this barrier by utilizing the entire bandwidth of the existing, copper network and providing voice as well as “high speed” information transmis sion capabilities simultaneously.

A DSL system comprises of DSL modem on the customer’s end, com monly referred to as CPE (customer premise equipment), which is connected to another DSL Modem, DSLAM (DSL Access Multiplexer) at the Local Call office (telephone exchange) .

The following figure, Figure 1 - A DSL System, gives a brief overview of a typical DSL system.

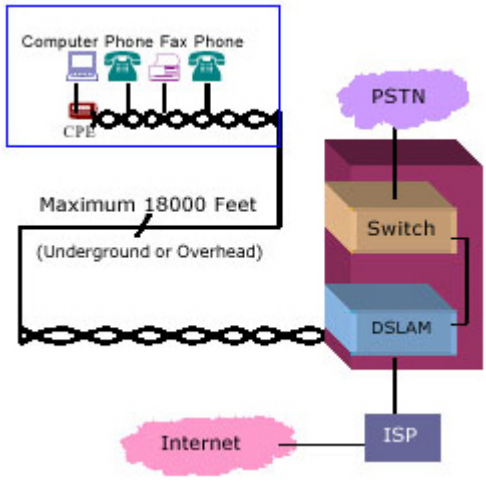

Figure 1 - A DSL System

Working

In normal PSTN network, speech signals, which originate from the telephone transmitter, travel till the local exchange. At the local exchange approxi mately 30 3 voice signals from 30 subscribers get bundled and sent over the E1/T1 line to another local exchange. As E1/T1 line support maximum of 2.048 Mbps and 1.544 Mbps respectively, it is impossible to send all these 30 (in case of E1) voice signals without filtering. For the same reason signals gets filtered via a band pass filter at the exchange before being transmitted on to the copper network between the exchanges, that is, a T1/E1 line. So PSTN and supporting local access networks have been designed with guidelines that limit the transmission to a 3300 Hz analog voice channel.

The highest achievable information rate using that 3300 Hz spectrum, as discussed earlier is less than 33.6 Kbps. And thus dial up modems practically deliver data rate X2(interoperable ITU-T standard is V.90), we can achieve a one-way data transmis sion rate up to a maximum of 56 Kbps, provided that one end of transmission is terminated digitally 4 . Note that from subscriber to exchange we still have 1MHz band available, we are using only 3300 Hz out of that 1 MHz. To make use of this unused bandwidth, and hence to get benefit of higher data rate throughput, broad band access technologies like DSL have emerged. DSL provides a better data throughput by eliminating this wastage of the bandwidth. maximum up to 33.6 Kbps. But with the help of techniques like kflex and The DSL technique uses a DSLAM at the exchange to divert the information content to an ISP, instead of the T1/E1 lines. Refer to Figure 2 - A typical ADSL spectrum., which shows the typical frequency spec trum for both voice (telephone network) and data (DSL network).

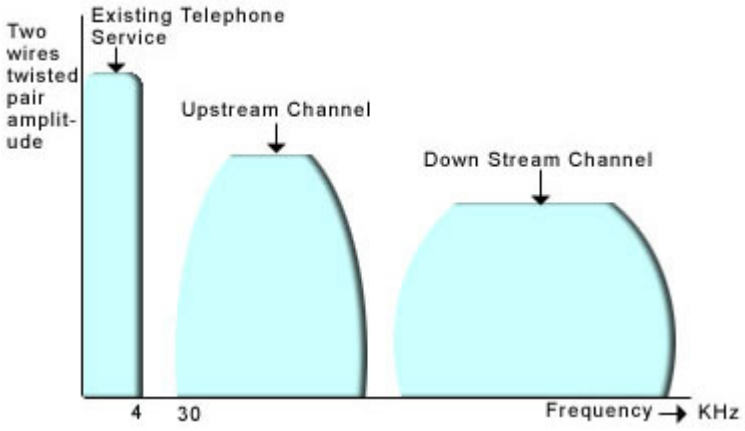

Figure 2 - A typical ADSL spectrum.

After this brief information about the DSL technology, one can now compare and contrast between DSL modems and dial up modems. Following are a few marked differences in these two technologies.

DSL Modems	Dialup Modems
Always Connected	Need to dial up for connection.
High bit rate(a maximum of 58.2 Mbps downstream and 2.3 Mbps upstream)	Low bit rate (a maximum of 56 Kbps downstream and 33.6 Kbps upstream)
Complex. A high power DSP Processor/s needed.	Relatively simple. Can be implemented in normally available single fixed point DSP processor.
Connection and communication limited only to the local network. Beyond local telephone office it needs different infrastructure.	Can be connected to peer modem, which is also connected to PSTN anywhere in the world.
The telephone company office should modify infrastructures to bypass the switched telephone network and have their data routed to internet or video-on-demand operators.	The existing public switched telephone network is used.
Suitable for Internet browsing and video-on-demand like applications.	Can be use for data or fax transmission across the globe in real time.

Table 1 - DSL and Dial-up Modems.

Standards

Following are the standards available for DSL.

ITU-T

G.991.1: This Recommendation describes a transmission technique called High bit rate Digital Subscriber Line (HDSL), as a means for the transportation of several types of applications. This Recommendation defines the requirements for the individual HDSL transmission system, the transmission performance, the HDSL maintenance requirements and procedures.

G.992.1: This Recommendation describes the interface between the telecommunications network and the customer installation in terms of their interaction and electrical characteristics. The requirements of this Recommendation apply to a single asymmetric digital subscriber line (ADSL). This is also called as G.lite.

G.992.2: Splitterless ADSL

G.994.1 : Handshake procedures for DSL transceivers.

G.997.1: Physical layer management for DSL transceivers.

G.996.1: Test Procedures for DSL transceivers.

DSL Infrastructure

The infrastructure requirements for DSL can be logically and functionally divided for two different types of equipment dependng upon their location, namely…

nCustomer Premises Equipment (or CPE)
nCentral Office Equipment (or COE), like DSLAM.

In the following sections we briefly explain the basic infrastructure requirements for both of the above mentioned equipment.

Infrastructure requirement for CPE : At the customer end, the operator must install a **POTS splitter to** separate the high and low frequencies. Low frequencies are passed to the phone, while high frequencies are delivered to the Customer Premises Equipment **(CPE**). The common assumption is that the CPE is an **ADSL modem** (technically called an *ATU*-R) attached to a personal computer, although ADSL could also serve other equipment such as a television (for Video-on-demmand). An ADSL modem performs the same task as a conventional modem in that, it converts the digital computer signalsinto analog signals that can be sent down a telephone line. The modem organizes the aggregate data stream created by multiplexing channels together in 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, refer Figure 3 - ADSL : with splitter and external modem..

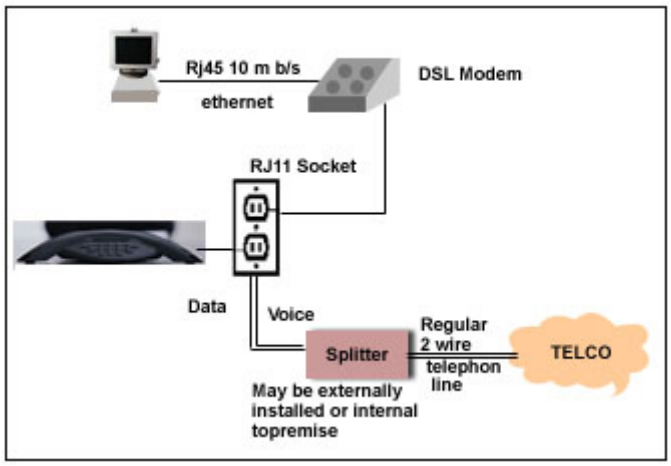

Figure 3 - ADSL : with splitter and external modem.

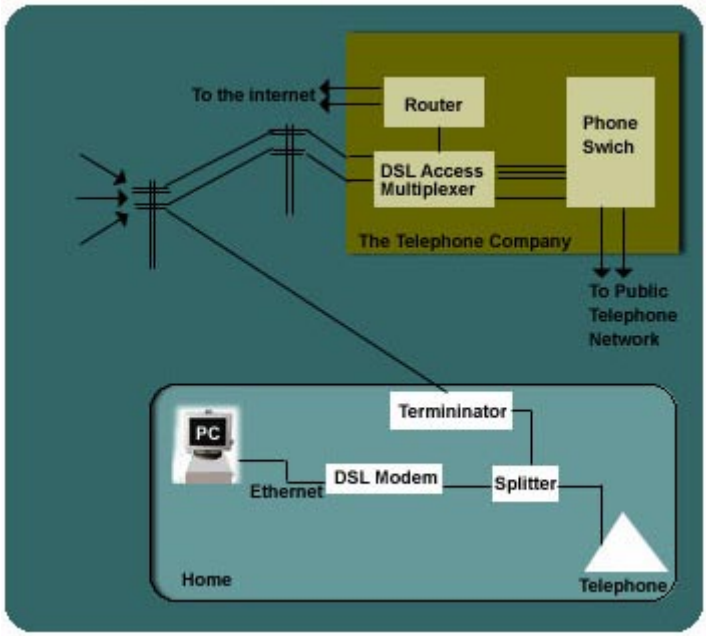

Figure 4 - The DSL Connection

Infrastructure requirement for COE : At the Telephone Company, the copper line passes into a splitter that performs a similar separation function as the splitter at the customer premises. Splitters are essentially *filter*s, which separate high frequency (ADSL) and low frequency (POTS) signals at network end and premises end. Voice signals are passed to switches onto the traditional telephone network, while data signals are routed to **line card**s, or banks of DSL modems. These line cards pass the data signals to a **DSL Access Multiplexer (DSLAM**). The DSLAM

then aggregates the data traffic from multiple DSL loops onto the backbone network for connection to the rest of the data network. A high-speed router, which is also known as BAS (broadband access server), can also be used as the backbone interface for the DSLAM.

Variants of DSL Modems

There are many variants of DSL. The "x" in xDSL stands for the various kinds of digital subscriber line technologies.

ADSL (Asymmetric Digital Subscriber Line): ADSL technology is called asymmetric as it allows more bandwidth downstream—from an NSP's central office to the customer site—than upstream from the subscriber to the central office. Only a small portion of bandwidth is available for upstream or user-interaction messages.

CDSL (Consumer DSL):CDSL is somewhat slower than ADSL but has the advantage that a splitter does not need to be installed at the user's end.

HDSL (High Bit-Rate Digital Subscriber Line):HDSL technology is symmetric, providing the same amount of bandwidth both upstream and downstream.

SDSL (Symmetric DSL): It will use a single copper-pair wire, and it will have a maximum operating range of 10,000 feet. Within its distance limitation, SDSL will be capable of accommodating applications that require identical downstream and upstream speeds.

RADSL (Rate-Adaptive DSL): Rate Adaptive Digital Subscriber Line (RADSL) is a simple extension of ADSL used to encompass and support a wide variety of data rates depending on the line's transmission characteristics.

I**DSL (ISDN DSL)**:IDSL is an ISDN CPE (customer premises equipment) talking to ISDN-compatible line cards that reside on the other end of the copper wire loop and terminate the ISDN signal independent of the telephone switch.

VDSL (Very High-bit-rate Digital Subscriber Line): VDSL technology is the fastest xDSL technology that promises much higher data rates over relatively short distances.

G.lite: G.lite is a new standards-based subset of ADSL .Its a lower-speed, lower-cost variant of ADSL that could be consumer installed and rapidly deployed by service providers. Now it is formally referred to as ITU-T G.992 standard, this is splitter less ADSL, easy to install , less complex and cost effective.

DSL TYPE	DATA RATE	DISTANCE LIMIT	APPLICATION
IDSL	128 Kbps	18,000 Feet on 24 gauge wire	Similar to ISDN BRI but only data no voice
CDSL	1 Mbps downstream; less upstream	18,000 FEET on 24 gauge wire	Splitter less home and small services
G.Lite	From 1.544 Mbps to 6 Mbps downstream, depending on the subscribed service	18,000 FEET on 24 gauge wire depending on the subscribed service	The standard ADSL; sacrifices speed for not having to install a splitter at the user's home or business
HDSL	1.544 Mbps duplex on two twisted-pair lines; 2.048 Mbps duplex on three twisted-pair lines	12,000 FEET on 24 gauge wire	T1/E1 service between server and phone company or within a company; WAN, LAN, server access (uses 2–3 wire pairs)
SDSL	1.544 Mbps duplex (U.S. and Canada); 2.048 Mbps (Europe) on a single duplex line downstream and upstream	12,000 FEET on 24 gauge wire	Same as for HDSL but requiring only one line of twisted-pair (uses 1 wire pair)
ADSL	1.544 to 6.1 Mbps downstream; 16 to 640 Kbps upstream	1.544 Mbps at 18,000 feet; 2.048 Mbps at 16,000 feet; 6.312 Mpbs at 12,000 feet; 8.448 Mbps at 9,000 feet	Used for Internet and Web access, motion video, video on demand, remote LAN access
RADSL	Adapted to the line, 640 Kbps to 2.2 Mbps downstream; 272 Kbps to 1.088 Mbps upstream	Transmission rates of up to 3.2 Mbps downstream and 1.1 Mbps upstream	Similar to ADSL
VDSL	12.9 to 52.8 Mbps downstream; 1.6 Mbps to 2.3 Mbps upstream	4500 feet at 12.96 Mbps	ATM networks; Fiber to the Neighborhood

Table 2- Variants of DSL.

Inside the DSL Modem

In the following sections we discuss the architecture of typical DSL components. Starting with the transceiver we give the entire block overview of the DSL modem.

The Simple DSL Transceiver

DSL frees the end-user from the limitations of voice bandwidth, providing bandwidth measured in the hundreds of kilohertz and enabling communications at least 100 times faster than that available over pure POTS, while still allowing you to make phone calls while your PC or fax is transmitting or receiving.

Figure 5 - Typical DSL modem architecture.

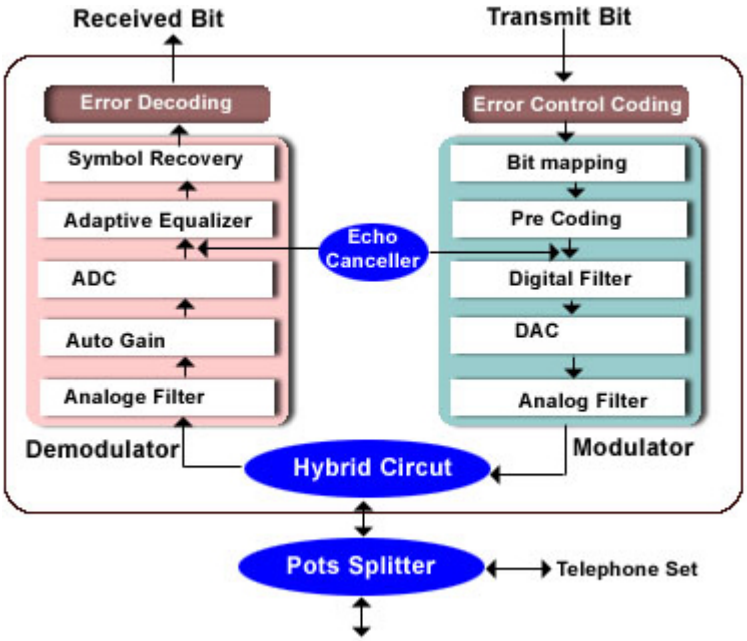

Figure 5 - Typical DSL modem architecture

The modulation / demodulation function of the DSL transceiver is digital. “Modulation” defines the process of converting each successive data symbol vector into a continuous time analog signal that represents the message corresponding to each successive group of bits. At the far end of the transmission, the receiving DSL unit converts these analog signals back into bit form, hence “demodulation.” Within the modulation/demodulation the different functions are echo cancellation, adaptive channel equalizing, symbol / bit conversion.

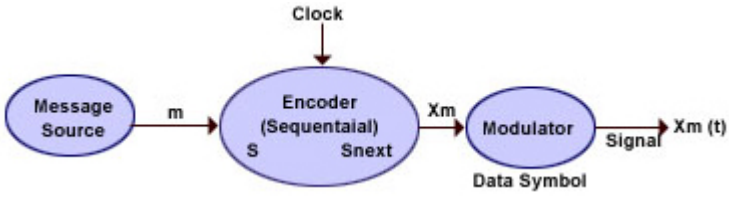

Figure 6 - Transmitter of Digital Transmission System.

Another major function of the DSL transceiver is coding/decoding -performed by a part of the transceiver as the encoder. The task of the encoder is to map data bits from a digital bit stream prior to modulation and transmission. The importance of coding varies depending on the flavor of xDSL in use. Earlier DSLs, such as IDSL and HDSL, require no coding at all. Later DSLs, ADSL for example, can use Reed-Solomon codes, trellis codes or both. In the most recent generation of DSL systems, HDSL2 being the prime example, coding forms a critical part of the DSL transceiver.The relationship of the encoder to the modulator in transmission appears above in Figure 6 -Transmitter of Digital Transmission System.

Besides the above modules, a DSL transceiver may also contain two other components. The first element is the hybrid circuit, an interface converter for conversion from four - wire, dual half-duplex to two-wire full duplex. The second element is the POTS splitter, a low-pass filter that separates the voice channel out from the DSL communication spectrum. The POTS splitter thus allows you to use your phone line for voice communication while simultaneously using it for data communication via modem, fax-machine, or other terminal equipment.

These, then, are the bare bones of an average DSL modem. The modem connects the customer premises to the local loop, the actual digital subscriber line. The digital signal may require regeneration while traveling along the local loop, a process carried out by repeaters. At the far end of the local loop lies the central office, the CO, where another DSL modem will pick up the digital transmission. A bird's eye view of this generic DSL architecture appearsbelow in Figure 7 - Generic DSL Reference Model.

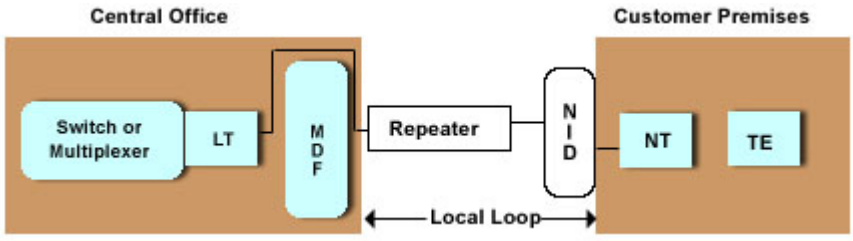

Figure 7 - Generic DSL Reference Model.

Central Office - Building where local loops connect to transmission links.
LT: Line Termination – Building where local loops connect to transmission and switching equipment.
Local Loop – Telephone wire connecting the CO to the customer premises.
MDF: Main Distributing Frame - Wire cross-connection field used to any loop to any Central Office equipment.
NID: Network Interface Device - Point of demarcation between the customer installation and the telephone company outside wire.
NT: Network Termination - DSL Modem at the customer end of the local loop.
Repeater – Signal regeneration device located near the midpoint of a cable.
TE: Terminal Equipment - End user equipment such as a personal computer or a telephone.

The role of DSLAM

We have now followed the path of data along the digital subscriber line from its commercial or residential source, via the local loop, to the CO. The local loop here terminates at the Main Distribution Frame (MDF), to be picked up by one of the CO's many DSL modems. If the form of DSL allows for the carrying of both analog and digital signals, a POTS splitter will separate out the signals. The analog signal will follow its time-honored path along the copper-wire infrastructure. For the digital signal, however, one step before the signal can be shot along to its destination.

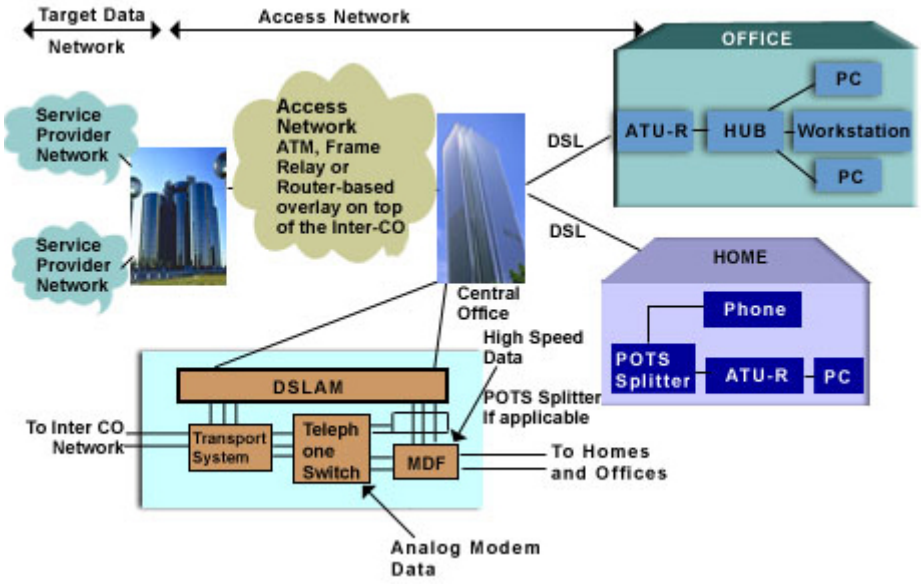

Figure 8 - DSL based services reference diagram.

Applications

DSL in Education: The Information Superhighway promises to revolutionize educational opportunities for children. But gaining access to this wealth of knowledge can be slow and costly for schools.

A traditional analog modem is relatively inexpensive, but offer speeds of only about 28.8 Kbps. A T-1 line offers great speeds – 1.544 Mbps – but T-1 lines can be cost prohibitive. The Solution Cutting-edge digital subscriber line (xDSL) technology offers schools a faster on-ramp to the Information Superhighway – at a cost within reach. With xDSL, students spend less time waiting and more time learning. xDSL uses existing telephone wires to transmit and receive data digitally at lightning-quick speeds. Typical speeds for downstream data are 2.560 Mbps. Upstream data flows at a rate of 1.088 Mbps. That's nearly 100 times faster than 28.8 analog modems and more than 40 times faster than ISDN.

Using xDSL technology, schools can connect to and from:

- the Internet
- other schools, community colleges and universities
- local and national libraries
- homes of teachers and other students
- district offices

Refer to Figure 9 - DSL in Education To get the picture of how a typical school can be connected in a network using xDSL technology.

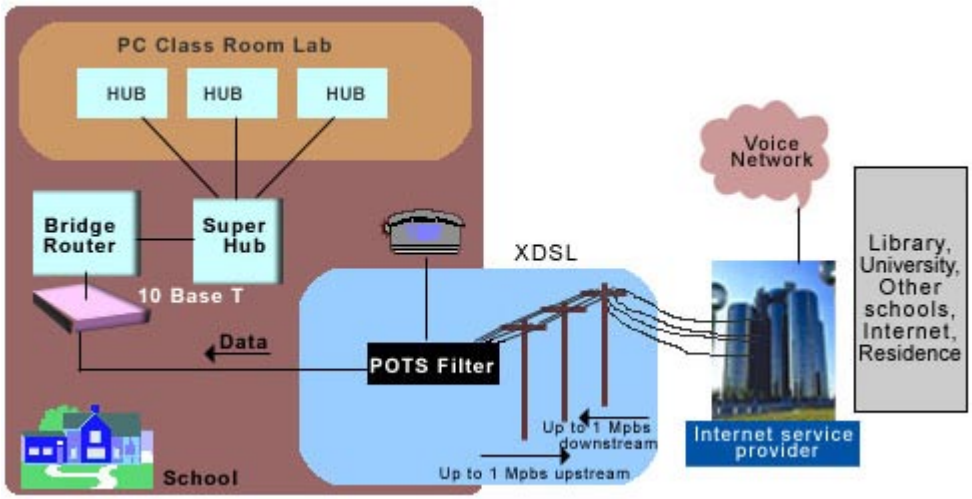

Figure 9 - DSL in Education

Voice over DSL:Voice-over-DSL (VoDSL) solutions propose to take advantage of high DSL access rates to carry one or more voice band services alongside the regular data stream. The term for additional voice lines is “derived lines”. Telephones that connect to derived lines are called derived phones. To take the advantage of this technology, network need to be a packet based network. Voice is transferred over a packet-based network, typically an ATM-based network in the context of DSL-based access.

In conformance to the ATM forum, “Voice and Multimedia Over ATM -Loop Emulation Service (LES) Using ATM Adaptation Layer 2 (AAL2)” [2]. The transport of a voice signal over a packet-based network requires two Voice Gateways (VGWs): one in an Integrated Access Device (IAD) at the customer premises and one in the Central Office (CO). In one direction, a VGW encodes and packetizes an incoming voice signal and produces a stream of ATM cells that it sends over the ATM network. In the other direction, the VGW dejitters an incoming stream of voice cells, decodes the payloads, and reconstructs the voice signal. The Telecommunication Standardization Sector International Telecommunication Union (ITU-T) Recommendations G.711 [10] and G.726 at 32 kb/s [11] are currently the codecs most used in VoDSL.

Some Acronyms

A short list of some of the other technical terms and acronyms that you may stumble across in trying to understand the DSL modem world.

ADSL	-	Asymmetric Digital Subscriber Line
AMI	-	Alternate Mark Inversion
AN	-	Access Network
ANSI	-	American National Standards Institute
ATM	-	Asynchronous Transfer Mode
ATU-C	-	ADSL Termination Unit - Central Office
ATU-R	-	ADSL Termination Unit - Remote
AWG	-	American Wire Gauge
BAS	-	Broadband access server
bps	-	Bits Per Second
BRI	-	Basic Rate Interface
CAP	-	Carrierless Amplitude and Phase
CCITT	-	Consultative Committee for International Telegraph and Telephone
CLEC	-	Competitive Local Exchange Carrier
CO	-	Central Office
CODEC	-	Coder/Decoder
COE	-	Central Office Equipment
CPE	-	Customer Premise (or Provided) Equipment
DCE	-	Data Communication (or Circuit-Terminating) Equipment
DMT	-	Discrete Multi-tone
DSL	-	Digital Subscriber Line
DSLAM	-	Digital Subscriber Line Access Multiplexer

DSP - Digital Signal Processor
DTE - Data Terminal (or Termination) Equipment
FDM - Frequency Division Multiplexing
HDSL - High bit-rate Digital Subscriber Line
IEC - Inter-Exchange Carrier
ISDL - ISDN Digital Subscriber Line
ISDN - Integrated Services Digital Network
ISP - Internet Service Provider
ITU - International Telecommunications Union
ITU-T - Telecommunication Standardization Sector International Telecommunication Union
Kbps - Kilobits Per Second
LAN - Local Area Network
Mbps - Megabits Per Second
MDF - Main Distribution Frame
MUX - Multiplexer
NAP - Network Access Provider
NSP - Network Service Provider
PBX - Public Branch Exchange
PC - Personal Computer
PCM - Pulse Code Modulation
POTS - Plain Old Telephone Service
PSTN - Public Switched Telephone Network
QAM - Quadrature Amplitude Modulation
QoS - Quality of Service
RADSL - Rate Adaptive Digital Subscriber Line
SDSL - Symmetric Digital Subscriber Line
SNR - Signal-to-Noise Ratio
SOHO - Small Office/Home Office
TCP - Transport Control Protocol
TELCO - Telephone Company
TDM - Time Division Multiplexing
UDSL - Unidirectional Digital Subscriber Line
UDSL - Unidirectional Digital Subscriber Line
VDSL - Very high bit-rate Digital Subscriber Line
VoIP - Voice over Internet Protocol
VPN - Virtual Private Network
WAN - Wide Area Network
xDSL - (generic) Digital Subscriber Line

NOTE: The Acronyms / definitions that are underlined are not used in the document, but are included since they are closely related to the field of DSL Modems and hence would be useful to the reader.

Acknowledgements & Bibliography

The following books and sites were used as a reference while the preparation of this white paper.

1. DSL Forum – www.adsl.com

2. “Gigabit Networks”, Author: Paul Izzo.

3. Tech guides – www.techguide.com

4. “Next Generation Modems”, Author: Gilbert Held.

About Wipro

Wipro provides Research and Development services to Telecom and Electronic product companies and software solutions to global corporate enterprises. In the Indian market, Wipro is a leader in providing IT solutions and services for the corporate segment offering system integration, network integration and IT services.Wipro Limited is the first SEI CMM Level 5 certified IT Services company operating in the global market. Wipro also has profitable presence in niche market segments of consumer products and lighting.

DSL Modems & Wipro

Wipro has successfully executed a number of projects over the years that have helped us to develop expertise in DSP, Modem and Multimedia technologies thus capable of delivering high quality services in all kinds of Modem Technologies. Wipro's expertise in the field of DSL technology ranges from development of independent components such as "DSL Access multiplexer", DSL device drivers, which include ADSL HAL (AHAL), ATM AAL5 UNI, RFC 1483 (RFC for bridged 802.3). Several implementations of the ATM and AAL protocols have been carried out successfully by Wipro. Wipro has designed and implemented the VDSL ASIC for a client.

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