An Overview of Digital Subscriber Line Technology
Technology basics, DSL equipment, types of DSL, comparison with cable, use by customers and eHealth support

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Table of Contents

I. Executive Summary ................................................................. 2
II. Introduction ............................................................................. 2
III. DSL Technology ................................................................. 3
IV. DSL versus Cable ............................................................... 7
V. Managing DSL with eHealth .................................................. 8
VI. References ............................................................................ 11
VII. Glossary ............................................................................... 12

I. Executive Summary

This document presents an overview of Digital Subscriber Lines, which are rapidly becoming popular for accessing corporate and Internet services. It provides a discussion of the technology, including descriptions of DSL equipment and types of DSL, an analysis of the pros and cons of DSL versus cable modem technology, and shows how eHealth can support customer networks featuring DSL.

II. Introduction

Digital Subscriber Line (DSL or xDSL) is an all-digital broadband replacement for modem technology. It supports megabit speeds over twisted pair copper cable and permits voice and data to be carried simultaneously on the same wire.

Since the late 1950s, modems have been used to transmit data over the public telephone network. They do this by modulating data onto voice frequencies, those below 4000 Hz, and carrying it over twisted pair copper cable to a central office. The central office forwards it into the telephone network and ultimately to its destination. This is a rather inefficient approach. Voice frequencies are not well suited to carrying data. Moreover, the telephone network has evolved from an analog medium to a mostly digital medium, forcing a modem transmission to undergo multiple analog-to-digital and digital-to-analog conversions in transit. These processes are slow and error prone and generally unable to manage more than a nominal 56 Kbps, and usually much lower speeds than that. In addition, modems require significant set-up time.
DSL offers several basic improvements on the modem. It dispenses with the need to modulate digital data into a voice signal, preserving it as digital throughout its transmission, and uses higher frequencies within the twisted pair cable, with correspondingly higher information carrying potential. In addition, unlike a modem, a DSL line can be kept permanently active, requiring no call setup delays. Finally, DSL permits the twisted pair to support data traffic and voice traffic simultaneously.

DSL technology takes advantage of an existing resource that was never intended to be used: the frequencies between 4000 Hz and about 1 MHz on copper cable. The ability to use these frequencies is a fortunate by-product of an old technology and has recently come into its own. There are a number of different versions of DSL which vary in the details of how they divide up the frequencies and how they trade off distance and speed.

One could argue that DSL is not new. Since the 1980s use has been made of frequencies above the voice band for digital transmission of data in the context of ISDN. ISDN bandwidths are small by today’s standards: 64 Kbps for each of two B channels and 16 Kbps for a single D channel, for a total of 144 Kbps. Nonetheless ISDN can claim to be the first DSL offering.

### III. DSL Technology

DSL is modulates bits onto electromagnetic frequencies and, as such, is an OSI physical layer technology. DSL uses several modulation techniques. Two of the most common are:

- **Discrete Multitone Technology (DMT)** which uses 256 narrow-band carriers, all transmitting simultaneously. It is similar to Orthogonal Frequency Division Multiplexing (OFDM) used in wireless LAN environments.

- **Carrierless Amplitude Modulation (CAP)**, licensed by Globe Span Technologies, Inc., which modulates the data onto two wide frequency bands in a manner similar to quadrature amplitude modulation (QAM) used by modems.

Other techniques include **Multiple Virtual Line (MVL)**, developed by Paradyne, which multiplexes the line into multiple virtual lines, and **Discrete Wavelet Multitone (DWMT)** from Aware Inc., which is intended to be an improved version of DMT.

All the versions of DSL divide the line bandwidth based on some form of frequency division multiplexing (FDM). FDM partitions the line into frequency bands and separates the higher frequency data traffic from the lower lying voice band. Upstream and downstream data frequencies can be separated using FDM as well, one band for upstream data and another for downstream, as shown in Figure 1. Alternatively, echo cancellation can be used. Echo cancellation permits both transmitted and received traffic to occupy the same frequency band by storing a copy of the transmitted signal and subtracting it off from the combined signal (transmitted plus received).
In general, data rates vary inversely with the length of the cable and directly with the frequency and weight of the wire. However, a variety of conditions, including noise, the presence of nearby loops and the effects of external electromagnetic fields, can affect the ability of a wire to sustain a data rate. Some of these conditions vary with time and the different versions of DSL may or may not adapt accordingly. Adaptive-rate DSLs, (such as RADSL, refer below) change the bandwidth offered to the user in response to changes in local loop conditions. If line conditions deteriorate and errors rates increase, the offered bandwidth drops to a more sustainable level. Conversely, if conditions improve the offered bandwidth increases accordingly. Fixed-rate DSLs, on the other hand, do not adapt to variations in local loop conditions. If conditions deteriorate and error rates drop below an acceptable level, the loop becomes inoperative and manual intervention may be required to restart the service, if it can be restarted at all.

The various versions of DSL all use some sort of error detection algorithm and some – for example ADSL and VDSL – utilize an error correction technique called forward error correction. This method organizes the data stream into blocks and appends an error correction code to each block, based on which errors can be detected and, to some extent, corrected. The tradeoff is extra overhead for improved reliability. Crosstalk is probably the major source of error in a DSL environment. It results from induced currents on the twisted pair caused by electromagnetic radiation from the wires used in neighboring twisted pairs.

![Figure 1. ADSL with Frequency Division Multiplexing](image-url)
DSL equipment

DSL equipment resides on the customer premise, on the local loop, and in the central office. Following are descriptions of key devices used in a DSL configuration, illustrated in Figure 2.

DSL Modems. Typically a DSL modem is associated with a user PC and may be internal or external. In some cases it might be part of a small router with LAN connections supporting a home or small business network.

Splitters. Some DSL technologies require installation of a splitter at the user-end to separate voice and data frequencies. From a service standpoint, this approach has its pros and cons. It requires a customer site visit, but provides enhanced performance. Splitting can also be provided at the central office, but at the cost of lower data rates than user-end splitting.

Digital Subscriber Line Access Multiplexers (DSLAMs). These devices are central office equipment. They accept input from remote DSL users and forward it to a DSL access concentrator (refer below). DSLAMs are essentially switches and typically use ATM technology. Examples of DSLAMs are the Cisco 6100 and 6200 series devices and the Lucent AnyMedia Access System.

Copper Cable. The local loop that connects the DSL modem with the DSLAM is twisted pair copper cable. The length of cable is critical in determining allowable DSL bandwidths and may exceed terrestrial distance to the central office. Within the United States, wire diameters are measured in American Wire Gauges (AWG); outside the United States they are measured in...
millimeters. In general, the higher the gauge, the smaller the wire diameter. Twenty-four gauge wire is 0.5 mm in diameter.

*Digital Loop Carriers (DLCs).* These are multiplexers that exist outside the central office, closer to the user than a DSLAM. They extend access to areas that are too far from the central office to receive service otherwise.

*DSL Access Concentrators.* These devices are edge routers that accept traffic from DSLAMs and forward it onto a service network. They terminate Point-to-Point Protocol (PPP) sessions and typically use Asynchronous Transfer Mode (ATM) technology. Cisco’s version of the Access Concentrator is the 6400 series.

**Types of DSL**

Following are descriptions of the different types of DSL available.

*Asymmetric Digital Subscriber Line (ADSL)* is by far the most common type of DSL, offering a variety of data rates, depending upon distance from the DSLAM. In the downstream direction it offers 1.544 Mbps at 18,000 feet (5500 m), 2.048 Mbps at 16,000 feet (4900 m), 6.312 Mbps at 12,000 feet (3700 m), and 8.448 Mbps at 9,000 feet (2700 m). In the upstream direction it offers up to 640 Kbps. ADSL is suitable for applications where downstream bandwidth requirements are considerable and upstream requirements relatively minimal, such as Web access where graphics or other bandwidth intensive data is received in the downstream direction but relatively little traffic is sent upstream. ADSL is asymmetric not only in terms of the data rates offered but also in terms of error probabilities. In general, signals attenuate over distance, and higher frequency signals attenuate faster than lower ones. In ADSL the downstream data stream uses higher frequencies than the upstream data stream (refer to Figure 1), so the downstream data tends to be more error-prone.

*Rate-Adaptive DSL (RADSL)* adjusts its delivery rate to the rate at which signals can be transmitted on the local loop. Local loops vary in terms of their ability to transport digital data. Rate adaptation “learns” the limitations of a local loop by testing individual carriers for their error tolerance, and accepting or rejecting them accordingly. The more carriers deemed acceptable, the higher the bandwidth that can be made available to the user. This can be anywhere from 640 Kbps to 2.2 Mbps downstream, and 272 Kbps to 1.088 Mbps upstream.

*G.Lite, DSL Lite, Splitterless ADSL or Universal ADSL* is a slower version of ADSL that does not require a splitter at the user end. It offers data rates of 1.544 to 6 Mbps downstream and 128 to 384 Kbps upstream, with a distance limit of 18,000 feet (5500 m) on 24 gauge wire.

*High bit-rate DSL (HDSL)* offers equal bandwidth upstream and downstream at T1 or E1 rates, T1 on two twisted pairs and E1 on three twisted pairs. There is a distance limit of 12,000 feet (3700 m) on 24 gauge wire.

*Symmetric DSL (SDSL)* also offers T1 or E1 data rates in each direction. SDSL is essentially the same service as HDSL but requires only a single twisted pair. It also has a distance limit of 12,000 feet (3700m) on 24 gauge wire.
Unidirectional DSL (UDSL). UDSL is a unidirectional version of HDSL.

Very high data rate DSL (VDSL) was designed for situations where optical fiber connections are nearby and the copper cable is required to go only a short distance to get to the fiber. It offers high data rates over short distances. The downstream rates – 12.96 Mbps at 4500 feet (1400 m), 25.92 Mbps at 3000 feet (900 m), 51.84 Mbps at 1000 feet (300 m) – are submultiples of SONET OC3 (155.52 Mbps). VDSL offers 1.5 to 2.3 Mbps upstream.

ISDN DSL (IDSL) is a combination of two ISDN B channels, each 64 Kbps, to obtain 128 Kbps in both directions. It has a distance limit of 18,000 feet (5500 m) on 24 gauge wire and is a data-only service, that is it cannot support data and voice simultaneously.

IV. DSL versus Cable

At present DSL and cable modem service providers are competing fiercely for the home and business access market. Both technologies provide high speed access to the Internet and other services, DSL over telephone wires and cable over the shared coaxial cable used for CATV. Predictably, exaggerated claims and counter claims have been made by both sides. While there are differences between the two technologies in terms of the features and quality of service provided, there does not appear to be any obvious winner. The relative desirability of one service over the other varies widely with individual circumstances and sweeping generalizations made by either side should be viewed skeptically. Following are some of the relevant issues.

DSL is a dedicated technology: a single user uses a twisted pair. Cable modems share bandwidth on a common length of coaxial cable. Much has been made of the fact that contention can result in reducing the bandwidth available to an individual user, but clearly the number of contending users, their anticipated loads, usage patterns and time of day need to be considered and evaluated. Moreover, it should be noted that beyond the central office or cable modem termination system, the Internet itself is a shared medium and the access link just one more shared facility in a sea of shared facilities.

For both technologies the offered bandwidths vary. Cable modems usually range from 500 Kbps to a couple of megabits per second downstream. DSL technologies offer bandwidth both within this range and beyond, but, as described above, depend heavily distance from the central office, gauge of the wires, presence of nearby wires, and so on.

A shared medium like cable offers some visibility into a neighbor’s data stream and hence some security vulnerability. With Microsoft Windows a user can often tell who else is on the same local cable segment. This problem does not occur with DSL. However, both DSL and cable are vulnerable to a hole in the Microsoft Windows file sharing feature. If this option is turned on and a password is not defined, anybody on the Internet can access the user’s files. With a cable modem a user can actually see which neighbors are present on the local segment, so cable is somewhat more vulnerable here. Nonetheless care in using Microsoft file sharing should help address security concerns.
DSL is vulnerable to crosstalk, as described above. As a practical matter, this means that there is some probability that crosstalk errors will corrupt a block of data and require the invocation of forward error correction or, in a serious enough case, retransmission by a higher level protocol. This limits the bandwidth available to a user and is generally factored into the bandwidth offered by the service. In extreme cases, however, crosstalk could reduce the effective bandwidth further or, if the problem is serious enough, preclude communication entirely. Again, much depends on individual circumstances.

Cable service tends to be less reliable than DSL. This is less a technological issue than a cultural one. DSL is offered by telephone companies which have historically been required to offer reliable service with minimal downtime. Cable service is offered by companies which have historically offered cable television, where reliability requirements are considerably less stringent. With time and competition, however, it is likely that any reliability differential will decrease.

In summary, there is no clear winner. The specifics of the individual service and the needs and circumstances of the particular customer are of overriding importance in suggesting one solution or the other.

V. Managing DSL with eHealth 5.0

DSL service providers are interested in growing and taking market share away from cable companies. The cable companies’ sales pitch against DSL generally involves its lack of reliability due to crosstalk, an issue we have treated above. DSL providers need a way to keep their service as reliable as possible in order to dispel this claim. To that end eHealth needs to monitor DSL performance, enhance troubleshooting, and assist in proactive capacity planning in much the same fashion as it would address any WAN technology.

Specifically, eHealth needs to monitor the following elements:

- access lines to the DSLAM
- the DSLAMs themselves
- lines from the DSLAM to the access concentrator
- the access concentrator

The DSLAMs are basically switches and the access concentrators are routers and we can employ Router/Switch Health to advantage here. The DSLAM-to-access-concentrator lines are typically ATM or Frame Relay so ATM Health or Frame Relay Health can be used. The access lines to the DSLAM, the DSL lines, can be addressed with DSL Health.

DSL Health is an extension to WAN Health that specifically monitors DSL access lines to the DSLAM. DSL elements support all WAN Health statistics as a subset of the available trend variables (for example, availability, packets, bytes, errors, discards and latency) most of which are datalink layer statistics. On top of this, DSL Health adds statistics that pertain to the physical
DSL layer. Thus users may view a problem at the higher level and drill down to the lower level to get a more detailed understanding of its causes.

All reports available for WAN elements are also available for DSL elements. On top of this, additional statistics are available for Trend and Top N reports, and At-a-Glance reports specific to DSL links are provided as well. For a sample At-a-Glance report, refer to Figure 3. Live Exception default profiles specific to DSL are also available.

In most cases where datalink layer errors or discards are present, concurrent errors will show up in the physical layer as well. The DSL At-a-Glance report has been designed to drill down from the various datalink layer statistics to relevant physical layer statistics in order to identify the root cause of a problem.

The eHealth reports can be brought to bear on the following problems:

**Determining Local Loop Quality.** A considerable problem facing DSL service providers is determining whether the local loop is of sufficient quality to support a desired level of service. Whether a DSL provider targets end users or wholesale customers, its main challenge is to focus its deployment on the areas of the local loop where plant quality is sufficient to support the desired bandwidth for high revenue services. The quality of the local loop determines the frequencies that can be supported, which determine the type of DSL and bandwidth that can be offered, which, in turn, determine revenue and market share. Several of the eHealth products described above can help characterize the performance of local loop configurations. For example, Figure 4 is a Top N report configured to search on attenuation, noise margin, and errors in order to find sections of the plant with acceptable performance.

**Identifying High Bandwidth Users.** Another problem facing service providers is identifying high bandwidth users so they can be offered a higher grade of service. Again, eHealth can be of use. Figure 5 is an example of a Top N report on bandwidth utilization upstream and downstream, and DSL speed upstream and downstream. It identifies existing users who are “bandwidth hogs.”

**Solving the Right Problems.** A third problem is providing proactive service assurance by identifying problems in the local loop and separating intermittent problems from more serious ones. DSL is subject to crosstalk and other types of interference and there is a need to distinguish momentary effects from true performance degradation in order to avoid dispatching a technician to investigate a non-problem. eHealth Live Exceptions permits alarming when the value of a variable of interest is above or below a threshold for a significant period of time. A live exception is generated when, say, the number of corrected blocks on a DSL line rises to an unacceptable value and remains there long enough to indicate a real problem.

**Verifying Improved Response Time.** A fourth concern is ensuring that DSL does indeed provide the user with improved response time, requiring the service provider to find sources of inordinate delay in the network. eHealth Service Response can be run from some suitable DSL client station equipped with a SystemEDGE agent to servers of interest, especially Web servers. If the Web servers where the content is stored are not up and running, or are running but performing poorly, the end user will still have problems. To that end the service provider can run SystemEDGE with an Apache or IIS plug-in on key web servers and monitor application performance with eHealth.
Figure 3. DSL At-A-Glance Report
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VII. Glossary

Asymmetric Digital Subscriber Line (ADSL). The most common type of DSL, offering a variety of data rates, depending upon distance from the DSLAM. ADSL is suitable for applications where downstream bandwidth requirements are considerable and upstream requirements light.

Carrierless Amplitude Modulation (CAP). A DSL modulation technique which utilizes two wide frequency bands in a manner similar to quadrature amplitude modulation (QAM) used by modems.
**Digital Loop Carrier (DLC).** A DSL multiplexer, similar to a DSLAM, but which exists outside the central office, closer to the user, extending access to areas that are too far from a central office to receive service otherwise.

**Digital Subscriber Line (DSL or xDSL).** An all-digital broadband replacement for modem technology. It supports megabit speeds over twisted pair copper cable and permits voice and data to be carried simultaneously on the same wire.

**Digital Subscriber Line Access Multiplexer (DSLAM).** A multiplexer in the central office that accepts input from remote DSL users and forwards it to a DSL access concentrator.

**Discrete Multitone Technology (DMT).** A DSL modulation technique that uses 256 narrow-band carriers transmitting simultaneously. It is similar to Orthogonal Frequency Division Multiplexing (OFDM) used in wireless LAN environments.

**DSL Access Concentrator.** A router that accepts input from DSLAMs and forwards it onto a service network.

**DSL Lite.** See G.Lite.

**DSL Modem.** A customer premise modulation device that provides DSL service, usually associated with a user PC. It may be internal or external to the PC.

**Forward error correction.** An error correction technique that organizes the data stream into blocks and appends an error correction code to each block, based on which errors can be detected and, to some extent, corrected. The tradeoff here is extra overhead for improved reliability.

**Frequency division multiplexing (FDM).** A data transport technique that transmits traffic simultaneously over multiple frequencies within the same medium.

**G.Lite.** A slower version of ADSL that does not require a splitter at the user end. Also called DSL Lite, Splitterless ADSL and Universal ADSL.

**High bit-rate DSL (HDSL).** A type of DSL that offers equal bandwidth upstream and downstream at T1 or E1 rates, T1 on two twisted pairs and E1 on three twisted pairs.
**ISDN DSL (IDSL).** A type of DSL that results from the combination of two ISDN B channels, each 64 Kbps, to obtain 128 Kbps in both directions.

**Rate-Adaptive DSL (RADSL).** A version of DSL that adjusts its delivery rate to the rate at which signals can be transmitted on the local loop.

**Splitter.** A device that separates voice and data frequencies on a local loop. It may be installed at the user end or the service end.

**Splitterless ADSL.** See G.Lite.

**Symmetric DSL (SDSL).** A type of DSL that offers T1 or E1 data rates in each direction. SDSL is similar to HDSL but requires only a single twisted pair.

**Unidirectional DSL (UDSL).** A unidirectional version of HDSL.

**Universal ADSL.** See G.Lite.

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