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How VDSL Works

White Paper

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The use of fast Internet connections has grown rapidly over the last few years. As more people buy home computers and create home networks, the demand for broadband (high-speed) connections steadily increases. Two technologies, cable modems and Asymmetric Digital Subscriber Line (ADSL), currently dominate the industry.

While both of these technologies provide Internet connections that are many times faster than a 56K modem, they still are not fast enough to support the integration of home services such as digital television and Video-on-Demand.

However, another DSL technology known as very high bit-rate DSL (VDSL) is seen by many as the next step in providing a complete home-communications/entertainment package. There are already some companies, such as U.S. West (part of Qwest now), that offer VDSL service in selected areas. VDSL provides an incredible amount of bandwidth, with speeds up to about 52 megabits per second (Mbps). Compare that with a maximum speed of 8 to 10 Mbps for ADSL or cable modem and it's clear that the move from current broadband technology to VDSL could be as significant as the migration from a 56K modem to broadband. As VDSL becomes more common, you can expect that integrated packages will be cheaper than the total amount for current separate services.

In this edition, you'll learn about VDSL technology, why it's important and how it compares to other DSL technologies. But first, let's take a look at the basics of DSL.

DSL Basics

A standard telephone installation in the United States consists of a pair of copper wires that the phone company installs in your home. A pair of copper wires has plenty of bandwidth for carrying data in addition to voice conversations. Voice signals use only a fraction of the available capacity on the wires. DSL exploits this remaining capacity to carry information on the wire without disturbing the line's ability to carry conversations.

Standard phone service limits the frequencies that the switches, telephones and other equipment can carry. Human voices, speaking in normal conversational tones, can be carried in a frequency range of 400 to 3,400 Hertz (cycles per second). In most cases, the wires themselves have the potential to handle frequencies of up to several-million Hertz. Modern equipment that sends digital (rather than analog) data can safely use much more of the telephone line's capacity, and DSL does just that.

ADSL uses two pieces of equipment: one on the customer end and one at the provider end:

- **Transceiver** - At the customer's location, there is a DSL transceiver, which may also provide other services.
- **DSL access multiplexer** (DSLAM) - The DSL service provider has a DSLAM to receive customer connections.

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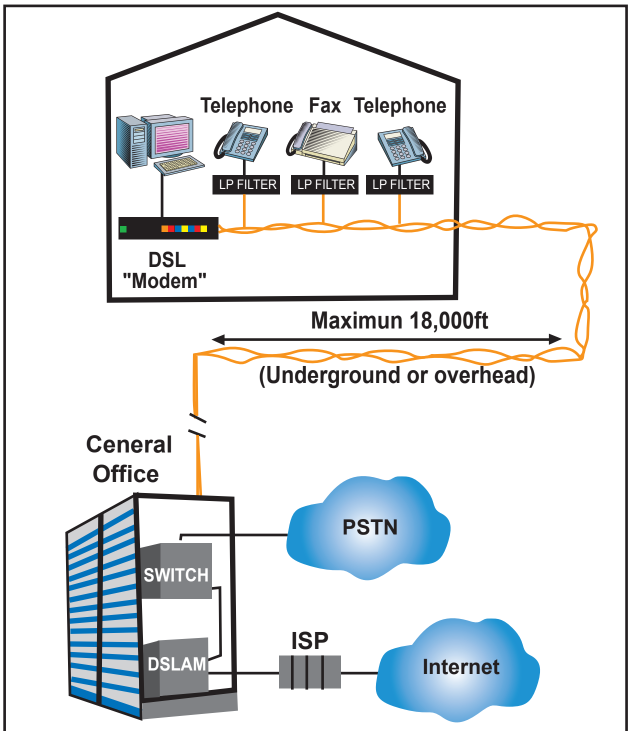

How an ADSL network is laid out

The DSLAM at the access provider is the equipment that really makes DSL happen. A DSLAM takes connections from many customers and aggregates them onto a single, high-capacity connection to the Internet. DSLAMs are generally flexible and able to support multiple types of DSL, as well as provide additional functions such as routing and dynamic IP address assignment for customers.

DSL is a distance-sensitive technology: As the connection's length increases, the signal quality and connection speed decrease. ADSL service has a maximum distance of 18,000 feet (5,460 m) between the DSL modem and the DSLAM, though for speed and quality of service reasons, many ADSL providers place an even lower limit on the distance. At the upper extreme of the distance limit, ADSL customers may experience speeds far below the promised maximums, whereas customers close the central office or DSL termination point may experience speeds approaching the maximum, and even beyond the current limit in the future.

You might wonder why, if distance is a limitation for DSL, it's not a limitation for voice telephone calls, too. The answer lies in small amplifiers, called loading coils, that the telephone company uses to boost voice signals. These loading coils are incompatible with DSL signals because the amplifier disrupts the integrity of the data. This means that if there is a voice coil in the loop between your telephone and the telephone company's central office, you cannot receive DSL service. Several other factors might disqualify you from receiving ADSL:

- **Bridge taps** - These are extensions, between you and the central office, that service other customers.
- **Fiber-optic cables** - ADSL signals can't pass through the conversion from analog to digital to analog that occurs if a portion of your telephone circuit comes through fiber-optic cables.
- **Distance** - Even if you know where your central office is (don't be surprised if you don't -- the telephone companies don't advertise their locations), looking at a map is no indication of the distance a signal must travel between your house and the office. The wire may follow a very convoluted path between the two points.

Fiber-optic cables, one of the major disrupting factors of ADSL, is actually what enables VDSL technology. In the next section, you'll find out why.

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VDSL Speed

VDSL operates over the copper wires in your phone line in much the same way that ADSL does, but there are a couple of distinctions. VDSL can achieve incredible speeds, as high as 52 Mbps downstream (to your home) and 16 Mbps upstream (from your home). That is much faster than ADSL, which provides up to 8 Mbps downstream and 800 Kbps (kilobits per second) upstream. But VDSL's amazing performance comes at a price: It can only operate over the copper line for a short distance, about 4,000 feet (1,200 m).

The key to VDSL is that the telephone companies are replacing many of their main feeds with fiber-optic cable. In fact, many phone companies are planning Fiber to the Curb (FTTC), which means that they will replace all existing copper lines right up to the point where your phone line branches off at your house. At the least, most companies expect to implement Fiber to the Neighborhood (FTTN). Instead of installing fiber-optic cable along each street, FTTN has fiber going to the main junction box for a particular neighborhood.

By placing a VDSL transceiver in your home and a VDSL gateway in the junction box, the distance limitation is neatly overcome. The gateway takes care of the analog-digital-analog conversion problem that disables ADSL over fiber-optic lines. It converts the data received from the transceiver into pulses of light that can be transmitted over the fiber-optic system to the central office, where the data is routed to the appropriate network to reach its final destination. When data is sent back to your computer, the VDSL gateway converts the signal from the fiber-optic cable and sends it to the transceiver. All of this happens millions of times each second!

ADSL and VDSL are just two representatives of the DSL spectrum.

Comparing DSL Types

There are several variations on DSL technology. In fact, there are so many that you will often see the term xDSL, where x is a variable, when the discussion is about DSL in general.

- **Asymmetric DSL (ADSL)** - It is called "asymmetric" because the download speed is greater than the upload speed. ADSL works this way because most Internet users look at, or download, much more information than they send, or upload.
- **High bit-rate DSL (HDSL)** - Providing transfer rates comparable to a T1 line (about 1.5 Mbps), HDSL receives and sends data at the same speed, but it requires two lines that are separate from your normal phone line.
- **ISDN DSL (ISDL)** - Geared primarily toward existing users of Integrated Services Digital Network (ISDN), ISDL is slower than most other forms of DSL, operating at fixed rate of 144 Kbps in both directions. The advantage for ISDN customers is that they can use their existing equipment, but the actual speed gain is typically only 16 Kbps (ISDN runs at 128 Kbps).
- **Multirate Symmetric DSL (MSDSL)** - This is Symmetric DSL that is capable of more than one transfer rate. The transfer rate is set by the service provider, typically based on the service (price) level.
- **Rate Adaptive DSL (RADSL)** - This is a popular variation of ADSL that allows the modem to adjust the speed of the connection depending on the length and quality of the lin
- **Symmetric DSL (SDSL)** - Like HDSL, this version receives and sends data at the same speed. While SDSL also requires a separate line from your phone, it uses only a single line instead of the two used by HDS

- **Very high bit-rate DSL (VDSL)** - An extremely fast connection, VDSL is asymmetric, but only works over a short distance using standard copper phone wiring.
- **Voice-over DSL (VoDSL)** - A type of IP telephony, VoDSL allows multiple phone lines to be combined into a single phone line that also includes data-transmission capabilities.

The chart below provides a comparison of the various DSL technologies:

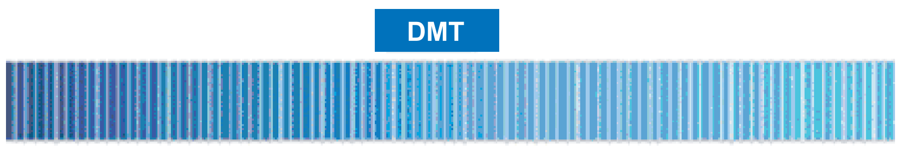
DSL Type	Max. Send Speed	Max. Receive Speed	Max. Distance	Lines Required	Phone Support
ADSL	800 Kbps	8 Mbps	18,000ft (5,500 m)	1	Yes
HDSL	1.54 Mbps	1.54 Mbps	12,000ft (3,650 m)	2	No
IDSL	144 Kbps	144 Kbps	35,000ft (10,700 m)	1	No
MSDSL	2 Mbps	2 Mbps	29,000ft (8,800 m)	1	No
RADSL	1 Mbps	7 Mbps	18,000ft (5,500 m)	1	Yes
SDSL	2.3 Mbps	2.3 Mbps	22,000ft (6,700 m)	1	No
VDSL	16 Mbps	52 Mbps	4,000ft (1,200 m)	1	Yes

As you can see, VDSL provides a significant performance boost over any other version. But for VDSL to become widely available, it must be standardized. In the next section, we'll talk about two potential VDSL standards.

Competing VDSL Standards

There are two competing consortiums that are pushing to standardize VDSL. The problem is that their proposed standards use carrier technologies that are incompatible with one another. The VDSL Alliance, a partnership between Alcatel, Texas Instruments and others, supports VDSL using a carrier system called Discrete MultiTone (DMT). According to equipment manufacturers, most of the ADSL equipment installed today uses DMT.

DMT divides signals into 247 separate channels, each 4 kilohertz (KHz, or 1,000 cycles per second) wide. One way to think about it is to imagine that the phone company divides your copper line into 247 different 4-KHz lines and attaches a modem to each one. You get the equivalent of 247 modems connected to your computer at once! Each channel is monitored and, if the quality is too impaired, the signal is shifted to another channel. This system constantly shifts signals, searching for the best channels for transmission and reception. In addition, some of the lower channels (those starting at about 8 KHz) are used as bidirectional channels, for both upstream and downstream information. Monitoring and sorting out the information on the bidirectional channels, and keeping up with the quality of all 247 channels, makes DMT more complex to implement than other carrier technologies, but also gives it more flexibility on lines of differing quality.

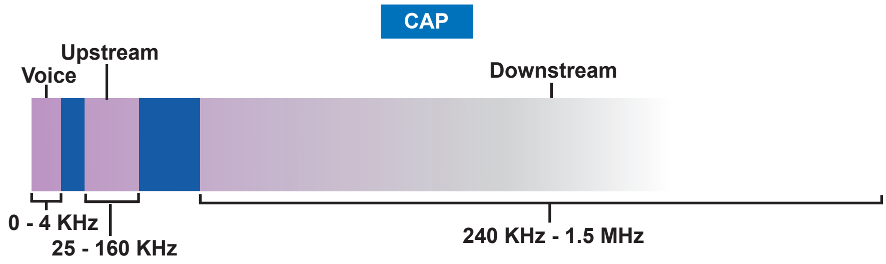


247 Channels (4 KHz each)

Discrete MultiTone divides the available carrier band into 247 distinct 4-KHz channels.

The other VDSL group is called the VDSL Coalition. Led by Lucent and Broadcom, the Coalition proposes a carrier system that uses a pair of technologies called Quadrature Amplitude Modulation (QAM) and Carrierless Amplitude Phase (CAP).

CAP operates by dividing the signals on the telephone line into three distinct bands: Voice conversations are carried in the zero- to 4-KHz band, which is in all standard phone circuits. The upstream channel (from the user to the server) is carried in a band between 25 and 160 KHz. The downstream channel (from the server to the user) begins at 240 KHz and goes up to a point that varies with such conditions as line length, line noise and the number of users in the switch, but it has a maximum of about 1.5 megahertz (MHz). This system, with the three channels widely separated, minimizes the possibility of interference between the channels on one line, or between the signals on different lines.



Carrier Amplitude Modulation divides the line into three distinct bands, with space between each band.

QAM is a modulation technique that effectively triples or quadruples the information sent over a line, depending on the version used. It accomplishes this by modulating (varying the shape of the carrier wave) and phase shifting (varying the angle of the carrier wave). An unmodulated signal provides for only two states, 1 or 0, which means that it can send a single bit of information per cycle. By sending a second wave that is shifted 90 degrees out of phase with the first one, and then modulating each wave so that there are two points per wave, you get eight states. This allows you to send 3 bits per cycle instead of just 1.

Why 3 bits? Remember that you are sending binary information. Two states equal a single bit (21 = 2). Four states are equivalent 2 bits (22 = 4). Eight states equal 3 bits (23 = 8).

By adding four more waves, shifted 15 degrees out of phase, you get 16 states and can send 4 bits per cycle (24 = 16). Adding another bit increases the number of phase shifts geometrically. To go beyond 4 bits per cycle becomes increasingly difficult because the number of necessary states doubles for each bit: 25 = 32, 26 = 64 and so on.

There is a possibility that VDSL will encompass both standards, with providers selecting which technology they will implement across their system.

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