General Guide to DSL

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VOICE AND DATA

DSL uses a second, higher frequency band (greater than 25 kHz) above the low frequency regime (5 kHz and below) used by voice communications. On the customer premises, a DSL filter is installed on each outlet for telephone handsets to remove the high frequency band, eliminating interference with the operation of the telephone set, and enabling simultaneous use.

HISTORY

Implementation of Digital Subscriber Line technology originally was part of the Integrated Services Digital Network (ISDN) specification published in 1984 by the CCITT and ITU as part of Recommendation I.120, later reused as ISDN Digital Subscriber Line (IDSL). Engineers have developed higher-speed DSL facilities such as High bit rate Digital Subscriber Line (HDSL) and Symmetric Digital Subscriber Line (SDSL) to provision traditional Digital Signal 1 (DS1) services over standard copper pair facilities. Consumer-oriented Asymmetric Digital Subscriber Line (ADSL), first tested at Bellcore in 1988, was designed to operate on existing lines already conditioned for BRI ISDN services, which itself is a switched digital service (non-IP), though most incumbent local exchange carriers (ILECs) provision Rate-Adaptive Digital Subscriber Line (RADSL) to work on virtually any available copper pair facility—whether conditioned for BRI or not.

The development of DSL, like many other forms of communication, can be traced back to Claude Shannon's seminal 1948 paper: *A Mathematical Theory of Communication*. Employees at Bellcore (now Telcordia Technologies) developed ADSL in 1988 by placing wide-band digital signals above the existing baseband analog voice signal carried between telephone company central offices and customers on conventional twisted pair cabling facilities.

Contrary to its name, while a DSL circuit provides *digital service*, it is actually not a digital signal. The underlying technology of transport across DSL facilities uses high-frequency sinusoidal carrier wave modulation, which is an analog signal transmission. A DSL circuit terminates at each end in a modem which modulates patterns of bits into certain high-frequency impulses for transmission to the opposing modem. Signals received from the far-end modem are demodulated to yield a corresponding bit pattern that the modem retransmits, in digital form, to its interfaced equipment, such as a computer, router, switch, etc. Unlike traditional dial-up modems, which modulate bits into signals in the 300–3400 Hz baseband (voice service), DSL modems modulate frequencies from 4000 Hz to as high as 4 MHz. This frequency band separation enables DSL service and plain old telephone service (POTS) to coexist on the same copper pair facility. Generally, higher bit rate transmissions require a wider frequency band, though the ratio of bit rate to bandwidth are not linear due to significant innovations in digital signal processing and digital modulation methods.

Early DSL service required a dedicated dry loop, but when the U.S. Federal Communications Commission (FCC) required ILECs to lease their lines to competing DSL service providers, shared-line DSL became available. Also known as DSL over Unbundled Network Element, this unbundling of services allows a single subscriber to receive two separate services from two separate providers on one cable pair. The DSL service provider's equipment is collocated in the same central office as that of the ILEC supplying the customer's pre-existing voice service. The subscriber's circuit is then rewired to interface with hardware supplied by the ILEC which combines a DSL frequency and POTS frequency on a signal copper pair facility.

On the subscriber's end of the circuit, inline low-pass DSL filters (splitters) are installed on each telephone to filter the high-frequency "hiss" that would otherwise be heard. Conversely, high-pass filters already incorporated in the circuitry of DSL modems filter out voice frequencies. Although ADSL and RADSL modulation do not use the voice-frequency band, nonlinear elements in the phone could otherwise generate audible intermodulation and may impair the operation of the data modem in the absence of low-pass filters.

Older ADSL standards can deliver 8 Mbit/s to the customer over about 2 km (1 ·25 miles) of unshielded twisted-pair copper wire. As of 2009, the latest standard, ADSL2+, can deliver up to 24 Mbit/s, depending on the distance from the DSLAM. Distances greater than 2 km (1.25 miles) significantly reduce the bandwidth usable on the wires, thus reducing the data rate. ADSL loop extenders increase these distances substantially.

Basic technology

Telephone engineers initially developed the local loop of the public switched telephone network (PSTN) to carry "plain old telephone service" (POTS) voice communication and signaling: no requirement for data communication as we know it today existed. For reasons of economy, the phone system nominally passes audio between 300 and 3,400 Hz, which is regarded as the range required for human speech to be clearly audible. This is known as voiceband or commercial bandwidth. The local telephone exchange (United Kingdom) or *central office* (United States) generally digitizes speech signals by using an analog-to-digital converter sampling at a rate of 8000 samples per second (and which captures 8-bit values producing a 64 kbit/s data stream). According to the Nyquist theorem, if an input audio signal injected into such an analog-to-digital converter contains frequency components higher than half of the sampling frequency, then such high frequency components will be aliased by the system, and so must be blocked at the input by an appropriate low-pass filter in order to prevent such effects. Therefore in this case input frequencies above 4000Hz will not be allowed to pass into the system and so attempting to achieve end-to-end communications by injecting arbitrarily high frequencies injected into the POTS through the normal voice path is not an option.

For a long time engineers believed it impossible to push a conventional phone-line beyond low-speed limits (typically under 9600 bit/s). In the 1950s ordinary twisted-pair telephone-cable often carried 4 MHz television signals between studios, suggesting that the such lines would allow transmitting many megabits per second. However, these cables had other impairments besides Gaussian noise, preventing such rates from becoming practical in the field. The 1980s saw the development of techniques for broadband communications that allowed the limit to be greatly extended.

The local loop connecting the telephone exchange to most subscribers has the capability of carrying frequencies well beyond the 3.4 kHz upper limit of POTS. Depending on the length and quality of the loop, the upper limit can be tens of megahertz. DSL takes advantage of this unused bandwidth of the local loop by creating 4312.5 Hz wide channels starting between 10 and 100 kHz, depending on how the system is configured. Allocation of channels continues at higher and higher frequencies (up to 1.1 MHz for ADSL) until new channels are deemed unusable. Each channel is evaluated for usability in much the same way an analog modem would on a POTS connection. More usable channels equates to more available bandwidth, which is why distance and line quality are a factor (the higher frequencies used by DSL travel only short distances).

The pool of usable channels is then split into two different frequency bands for upstream and downstream traffic, based on a preconfigured ratio. This segregation reduces interference. Once the channel groups have been established, the individual channels are bonded into a pair of virtual circuits, one in each direction. Like analog modems, DSL transceivers constantly monitor the quality of each channel and will add or remove them from service depending on whether they are usable.
One of Lechleider's contributions to DSL was his insight that an asymmetric arrangement offered more than double the bandwidth capacity of symmetric DSL. This allowed Internet Service Providers to offer efficient service to consumers, who benefitted greatly from the ability to download large amounts of data but rarely needed to upload comparable amounts. ADSL supports two modes of transport: fast channel and interleaved channel. Fast channel is preferred for streaming multimedia, where an occasional *dropped bit* is acceptable, but lags are less so. Interleaved channel works better for file transfers, where the delivered data must be error free but latency incurred by the retransmission of errored packets is acceptable.
Because DSL operates above the 3.4 kHz voice limit, it cannot pass through a load coil. Load coils are, in essence, filters that block out any non-voice frequency. They are commonly set at regular intervals in lines placed only for POTS service. A DSL signal cannot pass through a properly installed and working load coil, while voice service cannot be maintained past a certain distance without such coils. Therefore, some areas that are within range for DSL service are disqualified from eligibility because of load coil placement. Because of this, phone companies are endeavoring to remove load coils on copper loops that can operate without them, and conditioning lines to avoid them through the use of fiber to the neighborhood or node FTTN.
The commercial success of DSL and similar technologies largely reflects the advances made in electronics, that, over the past few decades, have been getting faster and cheaper even while digging trenches in the ground for new cables (copper or fiber optic) remains expensive. Several factors contributed to the popularization of DSL technology:

- Until the late 1990s, the cost of digital signal processors for DSL was prohibitive. All types of DSL employ highly complex digital signal processing algorithms to overcome the inherent limitations of the existing twisted pair wires. Due to the advancements of Very-large-scale integration (VLSI) technology, the cost of the equipment associated with a DSL deployment (a Digital subscriber line access multiplexer (DSLAM) at one end and a DSL modem at the other end) lowered significantly.
- A DSL connection can be deployed over existing cable. Such deployment, even including equipment, is much cheaper than installing a new, high-bandwidth fiber-optic cable over the same route and distance. This is true both for ADSL and SDSL variations.
- In the case of ADSL, competition in Internet access caused subscription fees to drop significantly over the years, thus making ADSL more economical than dial up access. Telephone companies were pressured into moving to ADSL largely due to competition from cable companies, which use DOCSIS cable modem technology to achieve similar speeds. Demand for high bandwidth applications, such as video and file sharing, also contributed to popularize ADSL technology.

Most residential and small-office DSL implementations reserve low frequencies for POTS service, so that (with suitable filters and/or splitters) the existing voice service continues to operate independent of the DSL service. Thus POTS-based communications, including fax machines and analog modems, can share the wires with DSL. Only one DSL "modem" can use the subscriber line at a time. The standard way to let multiple computers share a DSL connection uses a router that establishes a connection between the DSL modem and a local Ethernet, Powerline, or Wi-Fi network on the customer's premises.
Once upstream and downstream channels are established, a subscriber can connect to a service such as an Internet service provider.

TYPICAL SETUP & CONNECTION PROCEDURES

Physical connection must come first. On the customer side, the DSL Transceiver, or ATU-R, or more commonly known as a DSL modem, is hooked up to a phone line. The telephone company(telco) connects the other end of the line to a DSLAM, which concentrates a large number of individual DSL connections into a single box. The location of the DSLAM depends on the telco, but it cannot be located too far from the user because of attenuation, the loss of data due to the large amount of electrical resistance encountered as the data moves between the DSLAM and the user's DSL modem. It is common for a few residential blocks to be connected to one DSLAM.

When the DSL modem powers up it goes through a sync procedure. The actual process varies from modem to modem but generally involves the following steps:

1. The DSL transceiver performs a self-test.
2. The DSL transceiver checks the connection between the DSL transceiver and the computer. For residential variations of DSL, this is usually the Ethernet (RJ-45) port or a USB port; in rare models, a FireWire port is used. Older DSL modems sported a native ATM interface (usually, a 25 Mbit serial interface). Also, some variations of DSL (such as SDSL) use synchronous serial connections.
3. The DSL transceiver then attempts to synchronize with the DSLAM. Data can only come into the computer when the DSLAM and the modem are synchronized. The synchronization process is relatively quick (in the range of seconds) but is very complex, involving extensive tests that allow both sides of the connection to optimize the performance according to the characteristics of the line in use. External, or stand-alone modem units have an indicator labeled "CD", "DSL", or "LINK", which can be used to tell if the modem is synchronized. During synchronization the light flashes; when synchronized, the light stays lit, usually with a green color.

Modern DSL gateways have more functionality and usually go through an initialization procedure very similar to a PC boot up. The system image is loaded from the flash memory; the system boots, synchronizes the DSL connection and establishes the IP connection between the local network and the service provider, using protocols such as DHCP or PPPoE. The system image can usually be updated to correct bugs, or to add new functionality.

EQUIPMENT

The customer end of the connection consists of a terminal adaptor or in layman's terms "DSL modem". This converts data from the digital signals used by computers into a voltage signal of a suitable frequency range which is then applied to the phone line.

In some DSL variations (for example, HDSL), the terminal adapter connects directly to the computer via a serial interface, using protocols such as RS-232 or V.35. In other cases (particularly ADSL), it is common for the customer equipment to be integrated with higher level functionality, such as routing, firewalling, or other application-specific hardware and software. In this case, the equipment is usually referred to as a *DSL router* or *DSL gateway*.

Some kinds of DSL technology require installation of appropriate filters to separate, or "split", the DSL signal from the low frequency voice signal. The separation can take place either at the demarcation point, or with filters installed at the telephone outlets inside the customer premises. Either way has its practical and economical limitations. See ADSL for more information about this.

At the exchange, a digital subscriber line access multiplexer (DSLAM) terminates the DSL circuits and aggregates them, where they are handed off onto other networking transports. In the case of ADSL, the voice component is also separated at this step, either by a filter integrated in the DSLAM or by a specialized filtering equipment installed before it. The DSLAM terminates all connections and recovers the original digital information.

PROTOCOLS AND CONFIGURATIONS

Many DSL technologies implement an Asynchronous Transfer Mode (ATM) layer over the low-level bitstream layer to enable the adaptation of a number of different technologies over the same link.

DSL implementations may create bridged or routed networks. In a bridged configuration, the group of subscriber computers effectively connect into a single subnet. The earliest implementations used DHCP to provide network details such as the IP address to the subscriber equipment, with authentication via MAC address or an assigned host name. Later implementations often use Point-to-Point Protocol (PPP) or Asynchronous Transfer Mode (ATM) (Point-to-Point Protocol over Ethernet (PPPoE) or Point-to-Point Protocol over ATM (PPPoA)), while authenticating with a userid and password and using Point-to-Point Protocol (PPP) mechanisms to provide network details.

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