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Chapter Goals

- Identify and discuss different types of digital subscriber line (DSL) technologies.

- Discuss the benefits of using xDSL technologies.
- Explain how ADSL works.
- Explain the basic concepts of signaling and modulation.
- Discuss additional DSL technologies (SDSL, HDSL, HDSL-2, G.SHDSL, IDSL, and VDSL).

Digital Subscriber Line

Introduction

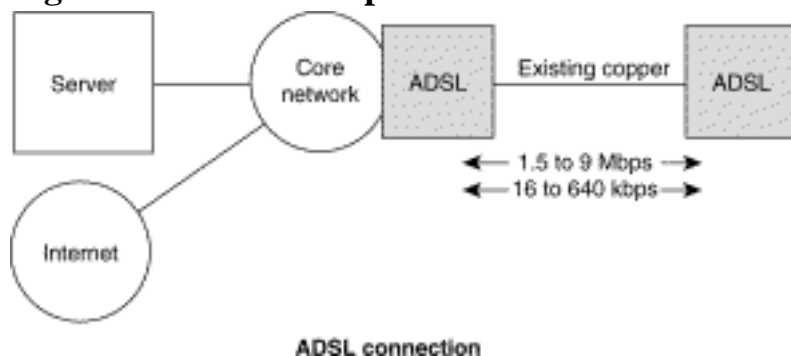
Digital Subscriber Line (DSL) technology is a modem technology that uses existing twisted-pair telephone lines to transport high-bandwidth data, such as multimedia and video, to service subscribers. The term *xDSL* covers a number of similar yet competing forms of DSL technologies, including ADSL, SDSL, HDSL, HDSL-2, G.SHDL, IDSL, and VDSL. xDSL is drawing significant attention from implementers and service providers because it promises to deliver high-bandwidth data rates to dispersed locations with relatively small changes to the existing telco infrastructure.

xDSL services are dedicated, point-to-point, public network access over twisted-pair copper wire on the local loop (last mile) between a network service provider's (NSP) central office and the customer site, or on local loops created either intrabuilding or intracampus. Currently, most DSL deployments are ADSL, mainly delivered to residential customers. This chapter focus mainly on defining ADSL.

Asymmetric Digital Subscriber Line

Asymmetric Digital Subscriber Line (ADSL) technology is asymmetric. It allows more bandwidth downstream—from an NSP's central office to the customer site—than upstream from the subscriber to the central office. This asymmetry, combined with always-on access (which eliminates call setup), makes ADSL ideal for Internet/intranet surfing, video-on-demand, and remote LAN access. Users of these applications typically download much more information than they send.

ADSL transmits more than 6 Mbps to a subscriber and as much as 640 kbps more in both directions (shown in Figure 21-1). Such rates expand existing access capacity by a factor of 50 or more without new cabling. ADSL can literally transform the existing public information network from one limited to voice, text, and low-resolution graphics to a powerful, ubiquitous system capable of bringing multimedia, including full-motion video, to every home this century.

Figure 21-1: The Components of an ADSL Network Include a Telco and a CPE

ADSL will play a crucial role over the next decade or more as telephone companies enter new markets for delivering information in video and multimedia formats. New broadband cabling will take decades to reach all prospective subscribers. Success of these new services depends on reaching as many subscribers as possible during the first few years. By bringing movies, television, video catalogs, remote CD-ROMs, corporate LANs, and the Internet into homes and small businesses, ADSL will make these markets viable and profitable for telephone companies and application suppliers alike.

ADSL Capabilities

An ADSL circuit connects an ADSL modem on each end of a twisted-pair telephone line, creating three information channels: a high-speed downstream channel, a medium-speed duplex channel, and a basic telephone service channel. The basic telephone service channel is split off from the digital modem by filters, thus guaranteeing uninterrupted basic telephone service, even if ADSL fails. The high-speed channel ranges from 1.5 to 9 Mbps, and duplex rates range from 16 to 640 kbps. Each channel can be submultiplexed to form multiple lower-rate channels.

ADSL modems provide data rates consistent with North American T1 1.544 Mbps and European E1 2.048 Mbps digital hierarchies (see Figure 21-2), and can be purchased with various speed ranges and capabilities. The minimum configuration provides 1.5 or 2.0 Mbps downstream and a 16-kbps duplex channel; others provide rates of 6.1 Mbps and 64 kbps for duplex. Products with downstream rates up to 8 Mbps and duplex rates up to 640 kbps are available today. ADSL modems accommodate Asynchronous Transfer Mode (ATM) transport with variable rates and compensation for ATM overhead, as well as IP protocols.

Figure 21-2: This Chart Shows the Speeds for Downstream Bearer and Duplex Bearer Channels

Downstream bearer channels	
n x 1.536 Mbps	1.536 Mbps 3.072 Mbps 4.608 Mbps 6.144 Mbps
n x 2.048 Mbps	2.048 Mbps 4.096 Mbps
Duplex bearer channels	
C channel	16 Kbps 64 Kbps
Optional channels	160 Kbps 384 Kbps 544 Kbps 576 Kbps

Downstream data rates depend on a number of factors, including the length of the copper line, its wire gauge, the presence of bridged taps, and cross-coupled interference. Line attenuation increases with line length and frequency, and decreases as wire diameter increases. Ignoring bridged taps, ADSL performs as shown in Table 21-1.

Table 21-1: Claimed ADSL Physical-Media Performance

Data Rate (Mbps)	Wire Gauge (AWG)	Distance (feet)	Wire Size (mm)	Distance (km)
1.5 or 2	24	18,000	0.5	5.5
1.5 or 2	26	15,000	0.4	4.6
6.1	24	12,000	0.5	3.7
6.1	26	9,000	0.4	2.7

Although the measure varies from telco to telco, these capabilities can cover up to 95 percent of a loop plant, depending on the desired data rate. Customers beyond these distances can be reached with fiber-based digital loop carrier (DLC) systems. As these DLC systems become commercially available, telephone companies can offer virtually ubiquitous access in a relatively short time.

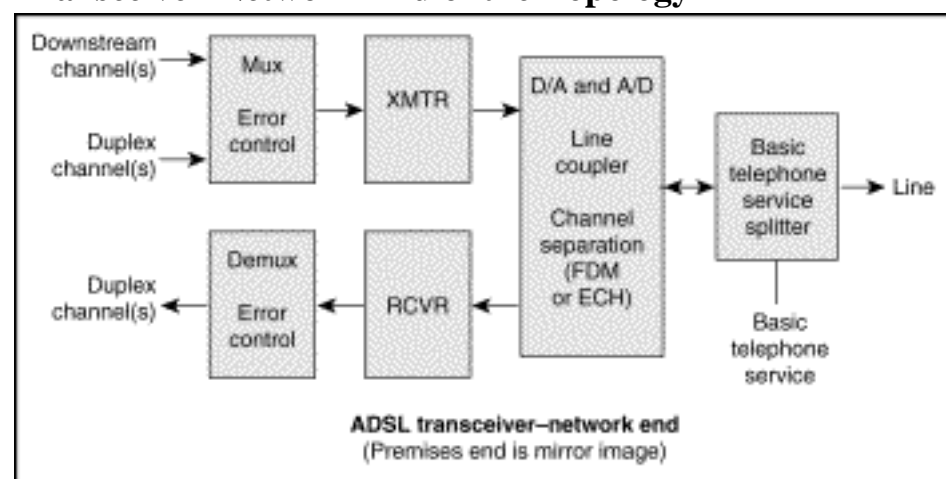
Many applications envisioned for ADSL involve digital compressed video. As a real-time signal, digital video cannot use link- or network-level error control procedures commonly found in data communications systems. Therefore, ADSL modems incorporate forward error correction that dramatically reduces errors caused by impulse noise. Error correction on a symbol-by-symbol basis also

reduces errors caused by continuous noise coupled into a line.

ADSL Technology

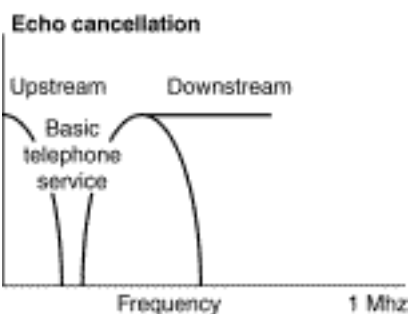
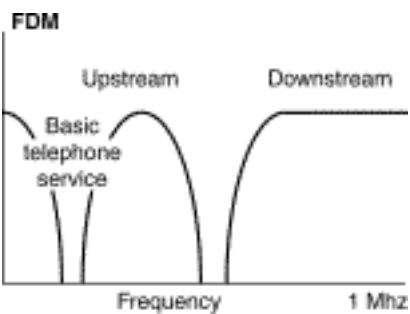
ADSL depends on advanced digital signal processing and creative algorithms to squeeze so much information through twisted-pair telephone lines. In addition, many advances have been required in transformers, analog filters, and analog/digital (A/D) converters. Long telephone lines may attenuate signals at 1 MHz (the outer edge of the band used by ADSL) by as much as 90 dB, forcing analog sections of ADSL modems to work very hard to realize large dynamic ranges, separate channels, and maintain low noise figures. On the outside, ADSL looks simple—transparent synchronous data pipes at various data rates over ordinary telephone lines. The inside, where all the transistors work, is a miracle of modern technology. Figure 21-3 displays the ADSL transceiver-network end.

Figure 21-3: This Diagram Provides an Overview of the Devices That Make Up the ADSL Transceiver-Network End of the Topology



To create multiple channels, ADSL modems divide the available bandwidth of a telephone line in one of two ways: frequency-division multiplexing (FDM) or echo cancellation, as shown in Figure 21-4. FDM assigns one band for upstream data and another band for downstream data. The downstream path is then divided by time-division multiplexing into one or more high-speed channels and one or more low-speed channels. The upstream path is also multiplexed into corresponding low-speed channels. Echo cancellation assigns the upstream band to overlap the downstream, and separates the two by means of local echo cancellation, a technique well known in V.32 and V.34 modems. With either technique, ADSL splits off a 4-kHz region for basic telephone service at the DC end of the band.

Figure 21-4: ADSL Uses FDM and Echo Cancellation to Divide the Available Bandwidth for Services



An ADSL modem organizes the aggregate data stream created by multiplexing downstream channels, duplex channels, and maintenance channels together into blocks, and it 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. At the user's option, the unit also can create superblocks by interleaving data within subblocks; this allows the receiver to correct any combination of errors within a specific span of bits. This, in turn, allows for effective transmission of both data and video signals.

Signaling and Modulation

This section includes the following:

- CAP and DMT Modulated ADSL
- ADSL Standards and Associations

CAP and DMT Modulated ADSL

DMT and *CAP* are line-coding methods for modulating the electrical signals sent over the copper wire in the local loop. Carrierless Amplitude and Phase (*CAP*) is a common line-coding method. *CAP* is a well-understood technology because of its similarity with QAM. Although *CAP* is well-understood and relatively inexpensive, some argue that it is difficult to scale because it is a single-carrier modulation technique and is susceptible to narrowband interference. *DMT* uses multiple carriers. At this point, *DMT* is capable of more speed than *CAP*. This is one reason that the ANSI committee T1E1.4 accorded it standards status in document T1.413.

This standard calls for 256 subbands of 4 KHz each, thereby occupying 1.024 GHz. Each subband can

be modulated with QAM 64 for clean subbands, down to QPSK. If each of the subbands can support QAM-64 modulation, then the forward channel supports 6.1 Mbps. On the return path are 32 subbands, with a potential for 1.5 Mbps.

CAP and DMT Compared

CAP is a single-carrier technique that uses a wide passband. DMT is a multiple-carrier technique that uses many narrowband channels. The two have a number of engineering differences, even though, ultimately, they can offer similar service to the network layers discussed previously.

Adaptive Equalization

Adaptive equalizers are amplifiers that shape frequency response to compensate for attenuation and phase error. Adaptive equalization requires that the modems learn line characteristics and do so by sending probes and looking at the return signals. The equalizer then knows how it must amplify signals to get a nice, flat frequency response. The greater the dynamic range, the more complex the equalization. ADSL requires 50 dB of dynamic range, complicating adaptive equalization. Only with recent advances in digital signal processing (number crunching) has it become possible to have such equalization in relatively small packaging.

Adaptive equalization is required for CAP because noise characteristics vary significantly across the frequency passband. Adaptive equalization is not needed for DMT because noise characteristics do not vary across any given 4-KHz subband. A major issue in comparing DMT with CAP is determining the point at which the complexity of adaptive equalization surpasses the complexity of DMT's multiple Fourier transform calculations. This is determined by further implementation experience.

Power Consumption

Although DMT clearly scales and does not need adaptive equalization, other factors must be considered. First, with 256 channels, DMT has a disadvantage regarding power consumption (and, therefore, cost) when compared with CAP. DMT has a high peak-to-average power ratio because the multiple carriers can constructively interfere to yield a strong signal. DMT has higher computational requirements, resulting in more transistors than the transceiver chips. Numbers are mostly proprietary at this point, but it is estimated that a single transceiver will consume 5 W of power, even with further advances. Power consumption is important because hundreds or thousands (as carriers dearly hope) of transceivers might be at the central office, or CEV. This would require much more heat dissipation than CAP requires.

Latency

Another issue for DMT is that latencies are somewhat higher than with CAP (15). Because each subband uses only 4 KHz, no bit can travel faster than permitted by a QAM-64. The trade-off between throughput and latency is a historical one in data communications and has normally been settled in the marketplace.

Speed

DMT appears to have the speed advantage over CAP. Because narrow carriers have relatively few equalization problems, more aggressive modulation techniques can be used on each channel. For CAP to achieve comparable bit rates, it might be necessary to use more bandwidth, far beyond 1 MHz. This creates new problems associated with high frequencies on wires and would reduce CAP's current advantage in power consumption.

ADSL Standards and Associations

The American National Standards Institute (ANSI) Working Group T1E1.4 recently approved an ADSL standard at rates up to 6.1 Mbps (DMT/ANSI Standard T1.413). The European Technical Standards Institute (ETSI) contributed an annex to T1.413 to reflect European requirements. T1.413 currently embodies a single terminal interface at the premises end. Issue II expands the standard to include a multiplexed interface at the premises end, protocols for configuration and network management, and other improvements.

The ATM Forum and the Digital Audio-Visual Council (DAVIC) have both recognized ADSL as a physical layer transmission protocol for UTP media.

Additional DSL Technologies

This section discusses the following DSL technologies:

- SDSL
- HDSL
- HDSL-2
- G.SHDSL
- ISDN Digital Subscriber Line (DSL)
- VDSL

SDSL

Symmetric Digital Subscriber Line (SDSL) is a rate-adaptive version of HDSL and, like HDSL, is symmetric. It allows equal bandwidth downstream from an NSP's central office to the customer site as

upstream from the subscriber to the central office. SDSL supports data only on a single line and does not support analog calls. SDSL uses 2B1Q line coding and can transmit up to 1.54 Mbps to and from a subscriber, or can be configured to offer a variable range of bandwidth up to 1.45 Mbps.

The symmetry that SDSL offers, combined with always-on access (which eliminates call setup), makes it a favorable WAN technology for small to medium businesses and branch offices, and can be an affordable alternative to dedicated leased lines and Frame Relay services. Because traffic is symmetrical, file transfer, web hosting, and distance-learning applications can effectively be implemented with SDSL.

HDSL

Originally developed by Bellcore, high bit-rate DSL (HDSL)/T1/E1 technologies have been standardized by ANSI in the United States and by ETSI in Europe. The ANSI standard covers two-pair T1 transmission, with a data rate of 784 kbps on each twisted pair. ETSI standards exist both for a two-pair E1 system, with each pair carrying 1168 kbps, and a three-pair E1 system, with 784 kbps on each twisted pair.

HDSL became popular because it is a better way of provisioning T1 or E1 over twisted-pair copper lines than the long-used technique known as Alternative Mark Inversion (AMI). HDSL uses less bandwidth and requires no repeaters up to the CSA range. By using adaptive line equalization and 2B1Q modulation, HDSL transmits 1.544 Mbps or 2.048 Mbps in bandwidth ranging from 80 contrast to the 1.5 MHz required by AMI. (AMI is still the encoding protocol used for the majority of T1.)

T1 service can be installed in a day for less than \$1,000 by installing HDSL modems at each end of the line. Installation via AMI costs much more and takes more time because of the requirement to add repeaters between the subscriber and the CO. Depending on the length of the line, the cost to add repeaters for AMI could be up to \$5,000 and could take more than a week.

HDSL is heavily used in cellular telephone buildouts. Traffic from the base station is backhauled to the CO using HDSL in more than 50 percent of installations. Currently, the vast majority of new T1 lines are provisioned with HDSL. However, because of the embedded base of AMI, less than 30 percent of existing T1 lines are provisioned with HDSL.

HDSL does have drawbacks. First, no provision exists for analog voice because it uses the voice band. Second, ADSL achieves better speeds than HDSL because ADSL's asymmetry deliberately keeps the crosstalk at one end of the line. Symmetric systems such as HDSL have crosstalk at both ends.

HDSL-2

HDSL-2 is an emerging standard and a promising alternative to HDSL. The intention is to offer a symmetric service at T1 speeds using a single-wire pair rather than two pairs. This will enable it to operate for a larger potential audience. It will require more aggressive modulation, shorter distances

(about 10,000 feet), and better phone lines.

Much of the SDSL equipment in the market today uses the 2B1Q line code developed for Integrated Services Digital Network. The Bell companies have insisted that using this SDSL at speeds higher than 768 kbps can cause interference with voice and other services that are offered on copper wire within the same wire bundle.

The biggest advantage of HDSL-2, which was developed to serve as a standard by which different vendors' equipment could interoperate, is that it is designed not to interfere with other services. However, HDSL-2 is full rate only, offering services only at 1.5 Mbps.

G.SHDSL

G.SHDSL is a standards-based, multirate version of HDSL-2 and offers symmetrical service. The advantage of HDSL-2, which was developed to serve as a standard by which different vendors' equipment could interoperate, is that it is designed not to interfere with other services. However, the HDSL-2 standard addresses only services at 1.5 Mbps. Multirate HDSL-2 is part of Issue 2 of the standard known as G.SHDSL, and is ratified by the ITU. G.SHDSL builds upon the benefits of HDSL-2 by offering symmetrical rates of 2.3 Mbps.

ISDN Digital Subscriber Line

ISDN digital subscriber line (IDSL) is a cross between ISDN and xDSL. It is like ISDN in that it uses a single-wire pair to transmit full-duplex data at 128 kbps and at distances of up to RRD range. Like ISDN, IDSL uses a 2B1Q line code to enable transparent operation through the ISDN "U" interface. Finally, the user continues to use existing CPE (ISDN BRI terminal adapters, bridges, and routers) to make the CO connections.

The big difference is from the carrier's point-of-view. Unlike ISDN, IDSL does not connect through the voice switch. A new piece of data communications equipment terminates the IDSL connection and shuts it off to a router or data switch. This is a key feature because the overloading of central office voice switches by data users is a growing problem for telcos.

The limitation of IDSL is that the customer no longer has access to ISDN signaling or voice services. But for Internet service providers, who do not provide a public voice service, IDSL is an interesting way of using POTS dial service to offer higher-speed Internet access, targeting the embedded base of more than five million ISDN users as an initial market.

VDSL

Very-High-Data-Rate Digital Subscriber Line (VDSL) transmits high-speed data over short reaches of

twisted-pair copper telephone lines, with a range of speeds depending on actual line length. The maximum downstream rate under consideration is between 51 and 55 Mbps over lines up to 1000 feet (300 m) in length. Downstream speeds as low as 13 Mbps over lengths beyond 4000 feet (1500 m) are also common. Upstream rates in early models will be asymmetric, just like ADSL, at speeds from 1.6 to 2.3 Mbps. Both data channels will be separated in frequency from bands used for basic telephone service and Integrated Services Digital Network (ISDN), enabling service providers to overlay VDSL on existing services. Currently, the two high-speed channels are also separated in frequency. As needs arise for higher-speed upstream channels or symmetric rates, VDSL systems may need to use echo cancellation.

Summary

ADSL technology is asymmetric, allowing more bandwidth for downstream than upstream data flow. This asymmetric technology combined with always-on access makes ADSL ideal for users who typically download much more data than they send.

An ADSL modem is connected to both ends of a twisted-pair telephone line to create three information channels: a high-speed downstream channel, a medium-speed duplex channel, and a basic telephone service channel. ADSL modems create multiple channels by dividing the available bandwidth of a telephone line using either frequency-division multiplexing (FDM) or echo cancellation. Both techniques split off a 4-kHz region for basic telephone service at the DC end of the band

Synchronous Digital Subscriber Line (SDSL) provides variable, symmetric, high-speed data communication up to 1.54 Mbps. But SDSL doesn't allow analog on the same line, as ADSL does. SDSL uses 2B1Q line coding, a technology employed in ISDN and T1 services. SDSL is a viable business option because of its capability to transmit high-speed data over longer distances from the CO and because of its ease of deployment made possible by its spectral compatibility.

High Bit-Rate DSL (HDSL) is a symmetric version of DSL that uses 2B1Q like SDSL, but over two-wire pairs. HDSL is targeted at business deployment because it offers full-rate symmetrical 1.5 Mbps service. HDSL-2 is a standards-based version of HDSL offering symmetrical 1.5 Mbps service like HDSL, but with a single twisted pair of wires. HDSL is full-rate and does not offer variable rates.

G.SHDSL does offer multirate service with symmetrical speeds of up to 2.3 Mbps.

ISDN digital subscriber line (IDSL) is similar in many ways to ISDN. The primary difference is that IDSL is always on and can reach speeds up to 512 kbps with compression. IDSL uses 2B1Q line coding and does not support analog.

On the other hand, IDSL does allow data communications over longer distances than other DSL options (up to 26,000 feet) and is considerably less expensive than ISDN service, in most cases. Because IDSL supports existing ISDN CPE, it makes it easy to convert from ISDN to IDSL.

Very-High-Data-Rate Digital Subscriber Line (VDSL) transmits high-speed data over short distances through twisted-pair copper telephone lines. VDSL technology is still in the definition stage, but additional research is required before it can be standardized. VDSL and ADSL are similar technologies. However, although VDSL transmits data at nearly 10 times the rate of ADSL, ADSL is the more complex transmission technology.

Review Questions

Q—*Name the current versions of DSL technology.*

A— ADSL, SDSL, HDSL, HDSL-2, G.SHDSL, IDSL, and VDSL.

Q—*What are the two-line coding methods used for ADSL?*

A—DMT and CAP.

Q—*Which versions of DSL offer symmetrical service?*

A—SDSL, HDSL, and HDSL-2.

Q—*What symmetrical version of DSL offers multirate service over a single pair of wire?*

A—G.SHDSL

Q—*How far of a reach can IDSL achieve from the CO?*

A—26,000 feet.

Q—*What downstream and upstream rates are proposed for VDSL?*

A—The maximum downstream rate under consideration is between 51 and 55 Mbps over lines up to 1000 feet (300 m) in length. Downstream speeds as low as 13 Mbps over lengths beyond 4000 feet (1500 m) are also common. Upstream rates in early models will be asymmetric, just like ADSL, at speeds from 1.6 to 2.3 Mbps.

For More Information

ADSL Forum (<http://www.adsl.com/>)

Glossary Terms

- **G.SHDSL**—Asymmetrical Digital Subscriber Line. The upstream data rate is different from the downstream (typically the downstream is greater than the upstream). It is applicable to many DSL technologies offered today; however, this term typically assumes DMT as defined in the ANSI T1.413 specification.
- **CPE**—Customer premises equipment, including devices such as CSU/DSUs, modems, and ISDN terminal adapters, required to provide an electromagnetic termination for wide-area network circuits before connecting to the router or access server. This equipment was historically provided by the telephone company, but it is now typically provided by the customer in North American markets.
- **CSU/DSU**—Channel service unit/data service unit. Provides electromagnetic termination of the digital (WAN) signal at the customer premises. Performs line conditioning and equalization functions, and responds to loopback commands sent from the central office. In North America, the customer supplies the device providing CSU/DSU functionality; outside North America, the telecommunications service provider usually provides this device.
- **DMT** —Discrete Multitone is the ANSI specified modulation technique for G.SHDSL (ANSI-T1.413). DMT is theoretically capable of more speed than CAP. The key providers of DMT are Alcatel, Amati, Aware/ADI, and Orckit.
- **Downstream**—Refers to the transmission of data from the central office (CO or COE) to the customer premise equipment (CPE).
- **HDSL**—High-speed Digital Subscriber Line. This is a symmetrical modulation technique that uses two or three pairs of wires.
- **HDSL2**—High-speed Digital Subscriber Line. This is a symmetrical modulation technique that can achieve speeds in the T1 (1.5 Mbps) range using one copper pair.
- **POTS** —Plain old telephone service.
- **QAM** —Quadrature amplitude phase modulation.
- **RG.SHDSL**—Rate Adaptive Digital Subscriber Line. This refers to the CAP2 and QAM technologies that use variable data rates to maximize the utilization of various loop lengths.

- **SDSL**—Symmetric Digital Subscriber Line. This indicates a subscriber line service that utilizes the same data rate for upstream and downstream. This term is applicable to MDSL and HDSL technologies.
- **Upstream**—Refers to the transmission of data from the customer premises equipment (CPE) to the central office equipment (CO or COE).
- **VDSL**—Very-High-Data-Rate Digital Subscriber Line. This is a high-speed asymmetrical service in the 10 to 25 Mbps range, typically limited to less than 5,000 feet. The targeted application for this technology is a hybrid fiber copper system (fiber to the neighborhood).

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