CHAPTER 1

INTRODUCTION TO DSL

Digital subscriber line (DSL) technology transforms an ordinary telephone line into a broadband communications link, much like adding express lanes to an existing highway. DSL increases data transmission rates by a factor of twenty or more by sending signals in previously unused high frequencies. DSL technology has added a new twist to the utility of twisted-pair telephone lines.

1.1 THE TELEPHONE LOOP PLANT

The twisted-wire pair infrastructure (known as the *loop plant*) connects customers to the telephone company network. The loop plant was designed to provide economical and reliable plain old telephone service (POTS). The telephone loop plant presents many challenges to high-speed digital transmission: signal attenuation, crosstalk noise from the signals present on other wires in the same cable, signal reflections, radio-frequency noise, and impulse noise. A loop plant optimized for operation of DSLs would be designed quite differently. Local-loop design practices have changed relatively little over the past 20 years. The primary changes have been the use of longer-life cables and a reduction in loop lengths via the use of the digital loop carrier (DLC). In recent years, primarily in the United States, many thousands of DLC remote terminals (DLC-RTs) have been placed in neighborhoods distant from the central office. Telephone and DSL service is provided directly from the DLC-RT. DSL performance is improved because the DSL signals traverse only the relatively short distance (generally, less than 12,000 feet) from the DLC-RT to the customer site. However, DSLs must cope with the huge embedded base of loop plant, some of which is 75 years old.

The term *loop* refers to the twisted-pair telephone line from a central office (CO) to the customer. The term originates from current flow through a looped circuit from the CO on one wire and returning on another wire. There are approximately 800 million telephone lines in the world.

The loop plant consists of twisted-wire pairs, which are contained within a protective cable sheath. In some parts of Europe and Asia the wires are twisted in four-wire units called "quads." Quad wire has the disadvantage[1] of high crosstalk coupling between the four wires within a quad. Within the CO, cables from switching and transmission equipment lead to a main distributing frame (MDF). The MDF is a large wire cross-connect frame where jumper wires connect the CO equipment cables (at the horizontal side of the MDF) to the outside cables (at the vertical side of the MDF). The MDF permits any subscriber line to be connected to any port of any CO equipment. Cables leaving the CO are normally contained in underground conduits with up to 10,000 wire pairs per cable and are called feeder cables, E-side, or F1 plant. The feeder cables extend from the CO to a wiring junction and interconnection point, which is known by many names: serving area interface (SAI), serving area concept box (SAC box), crossbox, flexibility point, primary cross-connection point (PCP). The SAI contains a small wire-jumper panel that permits the feeder cable pairs to be connected to any of several distribution cables. The SAI is at most 3,000 feet from the customer premises and typically serves 1,500 to 3,000 living units. The SAI is a wiring cross-connect field located in a small outside cabinet that permits the connection of any feeder wire pair to any distribution wire pair. The SAI predates DLC. The SAI contains no active electronics, and is located much closer to the customer than the carrier serving area (CSA) concept originally developed for DLC.

1.2 DSL REFERENCE MODEL

As shown in the generic DSL reference model in Figure 1.1, a DSL consists of a local loop (telephone line) with a transceiver at each end of the wires. The transceiver is also known as a modem (modulator/demodulator). The transceiver at the network end of the line is called the line termination (LT) or the transmission unit at the central end (TU-C). The LT may reside within a digital subscriber line access multiplexer (DSLAM) or a DLC-RT for lines fed from a remote site. The transceiver at the customer end of the line is known as the network termination (NT) or the transmission unit at the remote end (TU-R).

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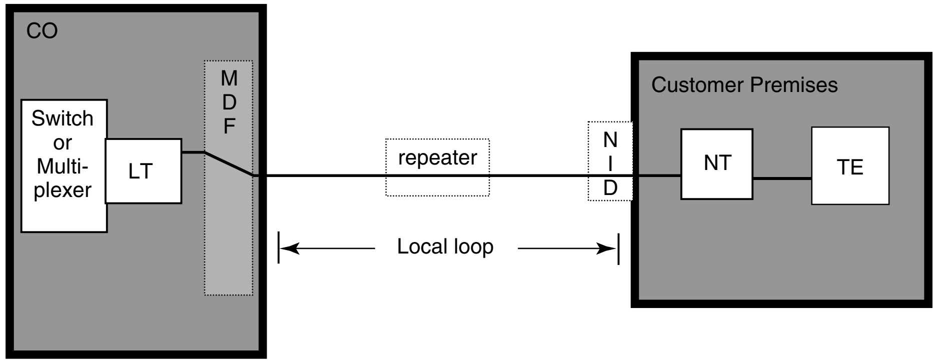
[1]Chapter 10 shows that such high crosstalk coupling can be an advantage when all four wires are used in a coordinated way by a single customer, but otherwise this characteristic is a disadvantage.



CO: Central Office—A building where local loops connect to transmission and switching equipment.

LT: Line Termination—DSL modem at the network end of the local loop.

MDF: Main Distributing Frame—A wire cross-connecting field used to connect any loop to any CO equipment.

Repeater: A signal regeneration device located near the mid-point of a cable. This enables transmission on long loops. Repeaters are not needed for the majority of loops.

Local Loop: The telephone wire connecting the CO to the customer premises.

NID: Network Interface Device—The 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.

TE: Terminal Equipment—End-user equipment such as a personal computer or a telephone.

Figure 1.1 DSL Reference Model

The majority of DSLs are served via copper lines extending all the way from the central office to the customer's premises as shown in Figure 1.1. To address DSL's limited line reach, a repeater may be placed near the midpoint of the copper line to boost the signal on the line. However, installation of midspan repeaters has a high material and labor cost. More often, DSL service for customers in areas distant from a CO have DSL service enabled by the placement of a DLC-RT in their neighborhood as shown in Figure 1.2. The DSL signals traverse the relatively short copper wire between the customer and the DLC-RT. The link between the CO and DLC-RT is usually optical fiber. Alternatively, distant areas may also be served via a DSLAM located at a remote site; sometimes the DSLAM may be located within a building having many customers.

Figure 1.3 shows the network architectures for a voice-band modem, private-line DSL, and switched DSL services. The voice-band modem transmission path extends from one customer modem, a local line, the public switched telephone network (PSTN), a second local line, and a second customer modem. In contrast, the extent of DSL transmission link is a customer-end modem (TU-R), a local line, and a network-end modem (TU-C), with the digital transport through the remainder of the network being outside the scope of the DSL transmission path. The private-line service is not switched within the network and thus provides a dedicated

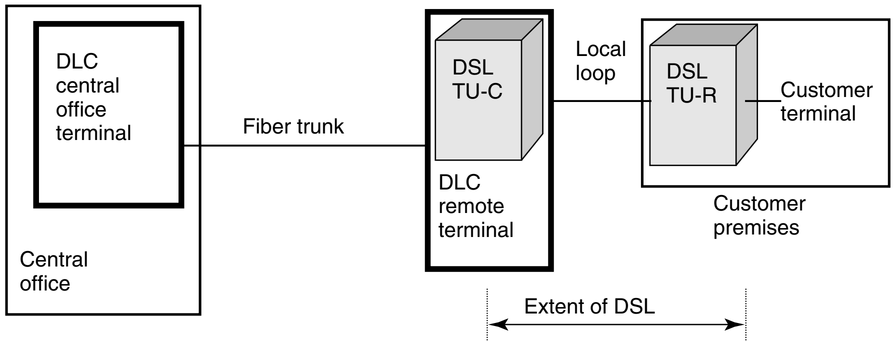


Figure 1.2 Digital Loop Carrier Reference Model

connection between two endpoints. The private-line architecture may contain a service-provisioned cross-connection within the central office. The switched DSL service permits the customer to connect to many end points simultaneously or sequentially. Often, the TU-C for the switched DSL service resides within a DSLAM. The switching or routing functions may reside within the DSLAM or in separate equipment.

1.3 THE FAMILY OF DSL TECHNOLOGIES

Several species of DSL have resulted from the evolution of technology and the market it serves. The earliest form of DSL, 144 kb/s basic rate ISDN, was first used for ISDN service in 1986, and then was later applied to packet mode ISDN DSL (IDSL), and local transport of multiple voice calls on a pair of wires (DAML: digital added main line). Basic rate ISDN borrowed from earlier voice band modem technology (V.34), and T1/E1 digital transmission technology (ITU Rec. G.951, G.952).

As shown in Figure 1.4, DSL transmission standards have evolved from 14.4 kb/s voice-band modems in the 1970s to 52 Mb/s VDSL in the year 2001. This has been an evolution, with each generation of technology borrowing from the prior generation.

High bit-rate DSL (HDSL) was introduced into service in 1992 for 1.5 Mb/s (using two pairs of wires) and 2 Mb/s (using two or three pairs of wires) symmetric transmission on local lines. HDSL greatly reduced the cost and installation time required to provide service by reducing the need for midspan repeaters and simplifying the line engineering effort. HDSL is widely used for private line services, and links to remote network nodes such as digital loop carrier remote terminals and wireless cell sites. In 2000, HDSL2 was introduced to accomplish the same bit-rate and line reach as HDSL but using one pair of wires instead of the two pairs required for HDSL. Both HDSL and HDSL2 operate over CSA (carrier serving area) length lines consisting of up to 12 kft[2] of 24 AWG wire, 9 kft of 26 AWG

[2] 1 kft equals 1,000 feet.

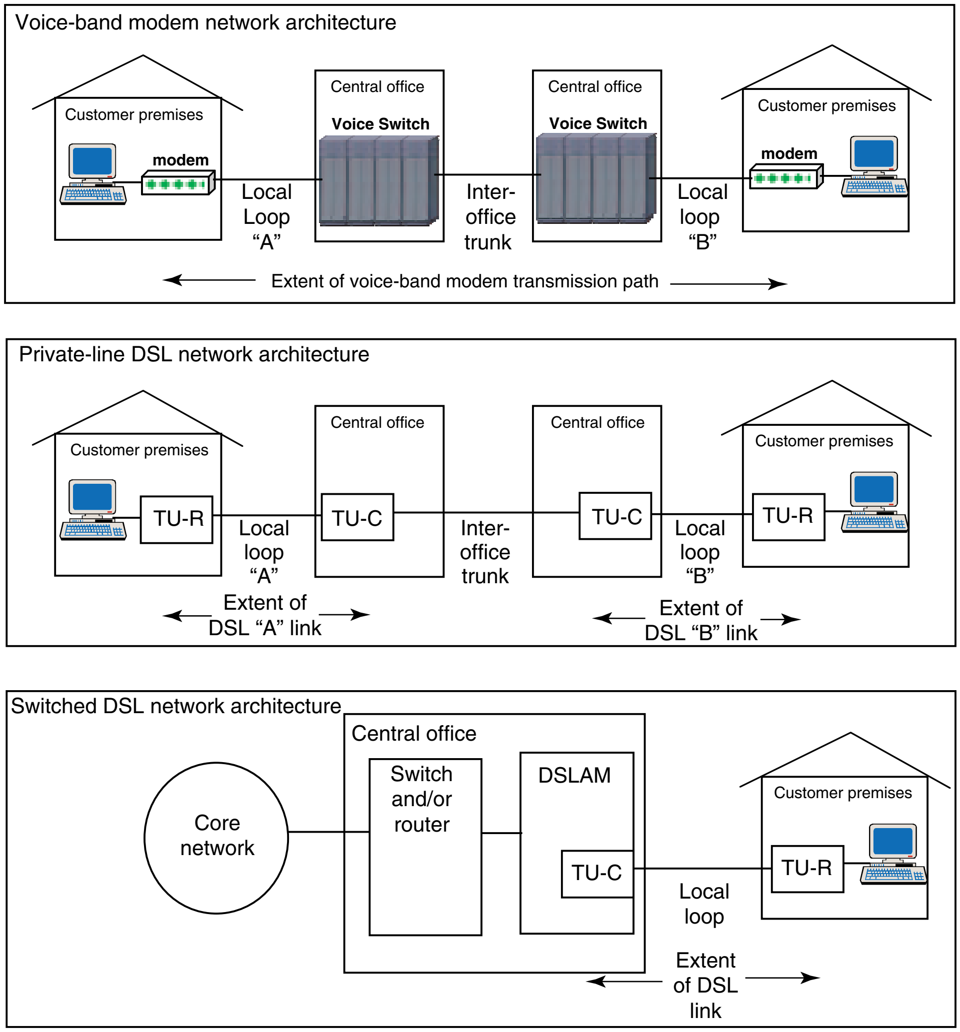


Figure 1.3 Comparative Network Architectures

wire, or a proportionate length of mixed wire gauges. HDSL2 is spectrally compatible with other services in the same cable within the CSA line lengths but may not be spectrally compatible if a midspan repeater is used to serve longer lines. HDSL4, using trellis-coded pulse amplitude modulation (TC-PAM) for two pairs of wires, achieves spectral compatibility for 1.5 Mb/s transport on longer loops. By reaching up to 11 kft on 26 AWG lines without repeaters, HDSL4 further reduces the need for repeaters. The complementary pair of technologies—HDSL2 (for CSA lines) and HDSL4 (for longer lines)—provide a lower cost and spectrally compatible means to provide symmetric 1.5 Mb/s for nearly all lines. Chapters 4 and 6 discuss HDSL2 and HDSL4, respectively. Chapter 6 also addresses the symmetric SHDSL technology.

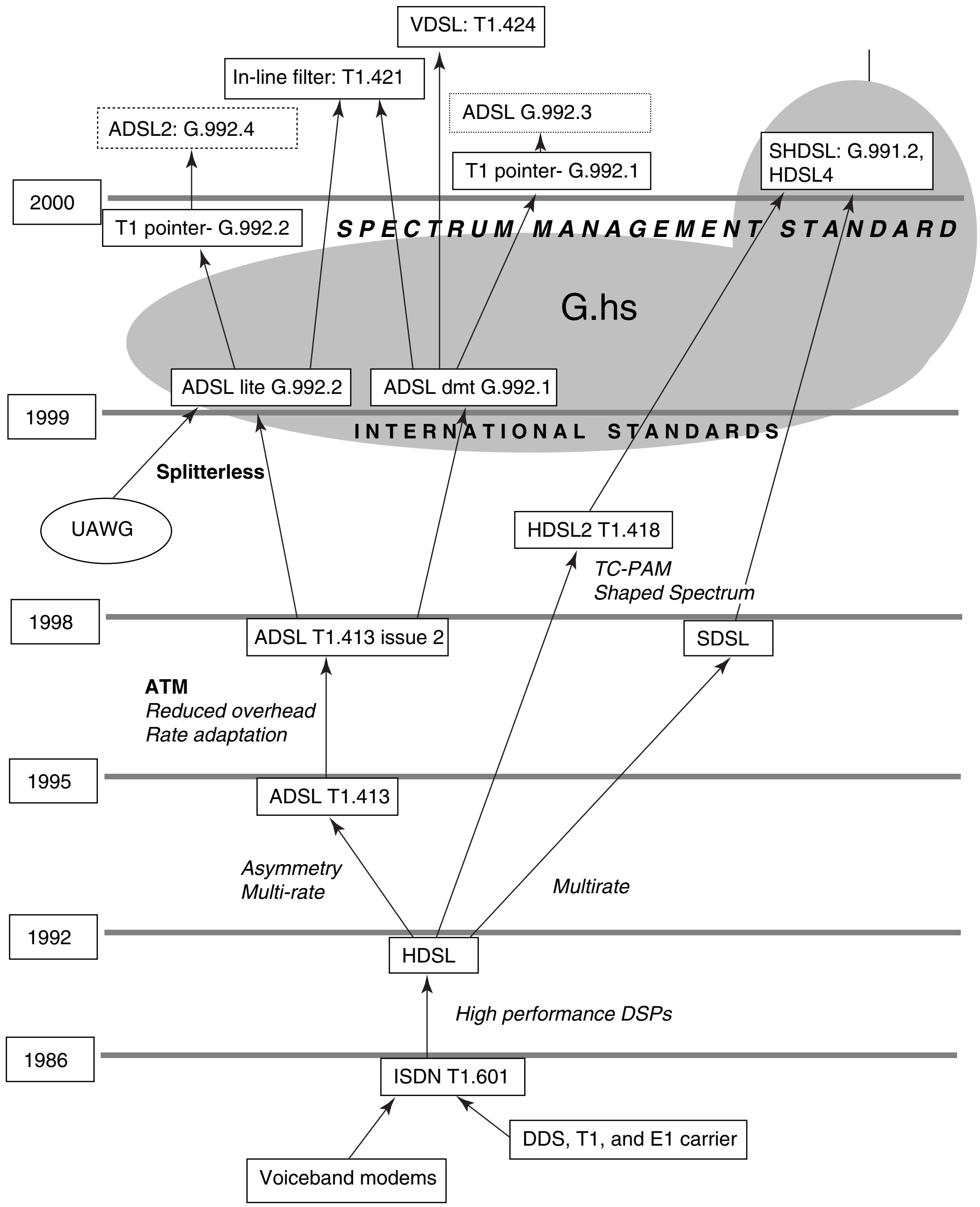


Figure 1.4 Evolution of DSL Technology (*Note:* Dates indicate publication of relevant standards.)

Asymmetric DSL (ADSL) service was introduced in 1995 and employed the following new technology aspects:

- Higher downstream bit rates are achieved via transmission asymmetry, using a wider bandwidth for downstream transmission and a narrower bandwidth for upstream transmission.
- Near-end crosstalk is reduced by partial or full separation of the upstream and downstream frequency bands.
- Simultaneous transport of POTS and data is achieved by transmitting data in a frequency band above voice telephony.[3]
- Use of advanced transmission techniques (trellis coding, Reed-Solomon codes with interleaving, and DMT modulation).
- Rate-adaptive transmission that adjusts to the highest bit rate allowed by the unique conditions for each line.

ADSL is widely used for applications benefiting from the bit-rate asymmetry, for example, high-speed Internet access and workstation access for small business offices and home work offices (SOHO). ADSL supports downstream bit-rates up to 8 Mb/s and upstream bit-rates up to 900 kb/s on short lines (less than 6 kft) with moderate line noise. However, to assure service to more lines with more noise, ADSL service is most often provided at bit-rates of 2 Mb/s or less downstream and 128 kb/s or less upstream. At mid-year 2002, there were 26 million ADSLs in service worldwide, with approximately 80 percent of the lines serving residential customers and 20 percent of the lines serving business customers. The early deployments of ADSL employed a splitter at both ends of the line to combine the 0–3.2 kHz analog voice signal with the ADSL signals in a higher frequency band. The development of the "G.lite" (ITU Rec. G.992.2) standard introduced the concept of enabling customer self-installation without a splitter at the customer end of the line. This reduced the labor cost to install the service. Field trials of G.lite demonstrated that an in-line filter must be inserted in series with most types of telephone sets to prevent problems for both the voice transmission as well as the digital transmission. Subsequently, it was determined that the in-line filters permitted effective operation of the full-rate ADSL (T1.413 and ITU Rec G.992.1), whereas G.lite is restricted to about 1.5 Mb/s downstream. As a result, the large majority of current ADSL installations use full-rate ADSL self-installed by the customer, placing an in-line filter by every telephone in their premises. Because ITU Recs. G.922.1 and G.992.2 were derived from the earlier T1.413 standard, all these ADSL standards are very similar, and most ADSL equipment supports all three standards. Chapter 3 discusses ADSL in more detail.

Single-pair high-bit-rate DSL (SHDSL) products were available by the end of 2000 based on the ITU Rec. G.991.2 standard. Like the nonstandard 2B1Q SDSL systems, SHDSL supports symmetric transmission at bit-rates from 192 kb/s to 2.32

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[3]In some parts of Europe, ADSL operates in a frequency band above Basic Rate ISDN (4B3T).

Table 1.1 Comparison of DSL Technologies

XDSL Technology	ADSL Full rate	ADSL-Lite "g.Lite"	HDSL, HDSL2, HDSL4	SDSL	SHDSL	IDSL	VDSL
Data rates	192k–8 Mb/s DS 64–900 kb/s US	256k–1.5 Mb/s DS 64–400 kb/s US	1.5 Mb/s symmetric	256k–2 Mb/s symmetric	192 k–2.3 Mb/s symmetric	128k or 144kb/s symm.	12–52 Mb/s DS 6–26 Mb/s symmetric
Loop reach mixed gauge wire	15 kft reach at lower rates	15 kft reach at lower rates	HDSL & HDSL2—9 kft, HDSL4—11 kft (×2 with repeater)	16 kft @ 256kb/s, 7 kft @ 1.5Mb/s	20 kft @ 256 kb/s, 9 kft @ 1.5 Mb/s	15 kft reach, repeater for ×2 reach	3 kft @ 26M/4M 1 kft @ 26 Mbs symmetric
Service types	Data & POTS Shared line	Data & POTS Shared line	DS1 private line	Data only	Data and optional digitized voice	Data only	Data and POTS
Principle applications	Internet access, data	Internet access, data	Data, voice trunking	Data	Data, voice	Data	Video, Internet access, data
Modulation	DMT	DMT	2B1Q-HDSL TC-PAM-HDSL2&4	2B1Q	TC-PAM	2B1Q	Multiple (CAP, QAM, DMT, FMT)
Common protocols	PPP over ATM	PPP over ATM	DS1	Frame Relay	ATM	Frame Relay	ATM
Standard	ITU G.992.1 T1.413	ITU G.992.2	ITU G.991.1-HDSL T1.418-HDSL2	None	ITU G.991.2	T1.601	T1 Trial use standard
Number of wire pairs	One pair	One pair	2 pairs: HDSL, HDSL4 1 pair: HDSL2	One pair	One pair (2 pair option doubles the bit rate)	One pair	One pair (1, 2 or 4 pairs in EFM area)

DS: Downstream—data rate towards the customer
US: Upstream—data rate from the customer
Symmetric: same data rate in both directions

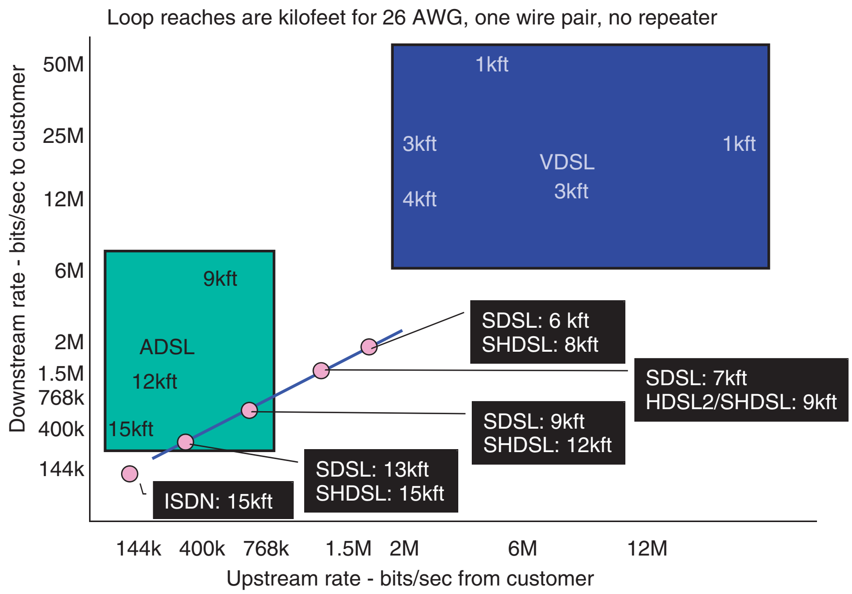

Figure 1.5 DSL Data Rates

Mb/s while providing at least 2,000 feet greater line reach than SDSL. Furthermore, the SHDSL specifications provided for the use of multiple pairs of wires and midspan repeaters to achieve greater bit-rates and line lengths. SHDSL uses trellis coded pulse amplitude modulation (TC-PAM), which is also used for HDSL2 and HDSL4. Chapter 6 discusses SHDSL in more detail.

Prestandard very high-bit-rate DSL (VDSL) systems were used in field trials in 2000. VDSL supports asymmetric bit-rates as high as 52 Mb/s downstream or symmetric bit-rates as high as 26 Mb/s. The key distinction of VDSL is its limitation to very short loops, as short as 1,000 feet for the highest bit-rates or up to about 4,000 feet for moderate data rates. The very short line length operation depends on shortening the copper line by placing an optical network unit (ONU) close to the customer site and then connecting one or more ONUs to the network with a fiber. Like ADSL, VDSL is a rate adaptive system that provides for simultaneous transmission of data and an analog voice signal. Chapter 7 discusses VDSL in more detail.

The term xDSL applies to most or all types of DSL technology. Chapter 5 discusses ITU G.994.1 (g.handshake), which DSL transceivers use to negotiate a common operating mode.

Figure 1.5 shows the upstream and downstream rates supported by the various DSL technologies with the symmetric technologies (ISDN, SHDSL, HDSL) residing along a line of symmetry, and the rate adaptive technologies (ADSL, VDSL) covering a broad range of bit-rates with the corresponding maximum line lengths indicated.

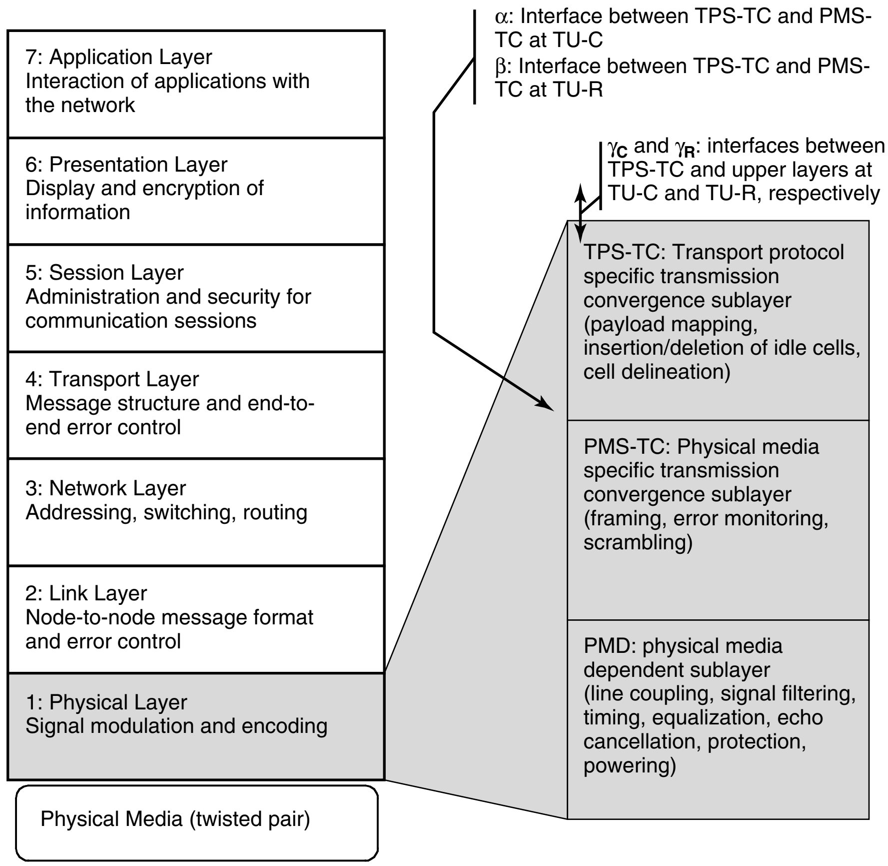

Figure 1.6 Protocol Reference Model

1.4 DSL PROTOCOL REFERENCE MODEL

Figure 1.6 shows the open systems interconnection (OSI) protocol reference model with additional detail shown for the physical layer. The structure within the physical layer is largely due to the contributions of Les Humphrey. The protocol reference model provides a structure to organize complex communications systems. The layered approach hides details of information from the subsystem, invoking the service of a particular layer. Thus, an application on a host requesting communication with its peer application does not need to know the details of its physical connection to a data network, communications used between itself and the network, or even the details of the protocols exchanged between the hosts supporting the application. The layered approach also simplifies the analysis of complex communication systems by segmenting the systems into several well-defined portions, facilitates reuse of portions of communications systems, and allows upgrades of portions of a communications system independently of each other.