

# CHAPTER 3

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## BASIC DATA COMMUNICATION TECHNOLOGY

### *Concepts Reinforced*

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Top-down model	I-P-O Model
Modulation techniques	Protocols and compatibility
Transmission services	Multiplexing

### *Concepts Introduced*

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Communications media	Cable modem technologies
Wireless point-to-point technologies	Serial technologies
Dial-up modem technologies	Internet service providers
	DSL technologies

### OBJECTIVES

After mastering the material in this chapter you should:

1. Understand the types of communication media available and the limitations and applications of each.
  2. Be able to compare and contrast basic point-to-point communication technologies such as RS-232, USB, IEEE-1394/Firewire, and Centronics parallel.
  3. Understand the applications and limitations of wireless point-to-point communication technologies, including IrDA and Bluetooth.
  4. Understand the role of an Internet service provider.
  5. Understand modem operation, comparative modem features, the importance of modem standards, and the cost/benefit analysis of various modem purchases.
  6. Understand the architecture and operation of digital subscriber line (DSL) technologies.
  7. Understand the architecture and operation of cable modem technologies.
  8. Be able to analyze and select the best Internet access technology for a given location.
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## ■ INTRODUCTION

This chapter begins an in-depth analysis of the OSI Network Reference Model layers that is carried forward through chapter 8. As detailed in chapter 1, the OSI Network Reference Model can easily be mapped onto other protocol models such as the TCP/IP model. This mapping will be detailed throughout the coming chapters.

This chapter introduces communication media, basic point-to-point data communications technologies, and Internet access technologies. It takes the basic concepts introduced in chapter 2 and maps them to real-world technologies that a typical student interacts with on a daily basis. In addition to technical details, emphasis is placed on the application and business implications of the technologies introduced.

## ■ PHYSICAL LAYER

The first layer of the OSI Network Reference Model, the **physical layer**, is responsible for the establishment, maintenance, and termination of physical connections between communicating devices. The physical layer transmits and receives a stream of bits. There is no data recognition at the physical layer. The physical layer is mapped onto the TCP/IP model as the bottom part of the network access layer that also contains the OSI datalink layer.

Specifically, physical layer operation is controlled by protocols that define the electrical, mechanical, and procedural specifications for data transmission. Strictly speaking, the physical layer does not define the specifications for media and connectors. These specifications are sometimes referred to as belonging to Layer zero of the model, as they underlie layer one.

## ■ COMMUNICATIONS MEDIA

Although communications media are technically not part of the OSI Network Reference or TCP/IP models, their importance cannot be understated. Without some sort of connection between two devices they will not be able to communicate; regardless of the hardware and protocols used. In this way media is analogous to a highway; it does not do you any good to have a Ferrari if you need to travel across a swamp that has no roads.

When two devices that have been working flawlessly cease to operate, there is a very good chance that the problem can be directly attributed to problems with the media connecting the devices. Perhaps the first mantra of network troubleshooting should be, “Check the physical layer.”

There are many different types of data communications media. This section details commonly used media, their characteristics, and typical application.

### **Not Twisted Pair**

The type of phone wire installed in most homes built prior to the mid-1990s consists of a tan plastic jacket containing four untwisted wires: red, yellow, green, and black. This cable is typically referred to as **four conductor station wire** or **RYGB**. While

capable of carrying an analog telephone call, this type of wire is not suitable for data transmission and should not be confused with unshielded twisted pair (UTP).

Another popular type of phone wiring is **flat gray modular** cable, also known as *gray satin* or *silver satin*. Inside this flat gray jacket are two, four, six, or eight wires, which are crimped into either RJ-11 (4 wire), RJ-12 (6 wire), or RJ-45 plugs (8-wire) using a specialized crimping tool. Premises phone wiring as well as phones; crimp tools, RJ plugs, and flat gray modular wire are attainable at nearly any hardware or department store.

Flat gray modular wire is not the same as twisted pair and is suitable only for carrying data at fairly slow speeds over short distances. For instance, this type of cable is often used between a PC or workstation and a nearby RJ-11 jack for access to the telephone system or to carry RS-232 serial communication signals.

## Unshielded Twisted Pair

Twisted-pair wiring consists of one or more pairs of insulated copper wire twisted around each other at varying lengths ranging from 2 to 12 twists per foot. The twisting is used as a mechanism to reduce interference between pairs and from outside sources such as electric motors and fluorescent lights that can cause data errors and necessitate retransmission. These individually twisted pairs are then grouped together and covered with a plastic or vinyl jacket, or sheath. No additional shielding is added before the pairs are wrapped in the plastic jacket. Thus, the completed product is known as **unshielded twisted pair** or **UTP**. The most common numbers of pairs combined to form the unshielded twisted pair cables are 2, 3, 4, and 25 pairs of twisted copper wire.

All UTP cables are not created equal. One of the common appeals of UTP is that it is often already installed in modern buildings for the purpose of carrying voice conversations from telephone handsets to a voice PBX. Most often, when the twisted-pair wiring for the voice PBX was installed, extra pairs were wired to each office location. Some people jump to the conclusion that they don't need to invest in any new wiring to carry data transmission throughout their building—they can just use the extra pairs of the existing UTP wiring. The problem lies in the fact that there are six different categories of UTP as specified by **EIA/TIA 568** (Electronics Industry Association/Telecommunications Industry Association). EIA/TIA 568 also specifies the following:

- The topology, cable types, and connector types to be used in EIA/TIA 568 compliant wiring schemes
- The minimum performance specifications for cabling, connectors and components—such as wall plates, punch down blocks, and patch panels to be used in an EIA/TIA 568 compliant installation

Although category 1 UTP, otherwise known as voice-grade, need only carry voice conversations with reasonable clarity, categories 3 to 6 (data-grade) cable must meet certain predefined electrical characteristics that assure transmission quality and speed. Before assuming that the UTP in a building is adequate for data transmission, have its transmission characteristics tested to be certain that these characteristics meet the listed data-grade UTP specifications. Figure 3-1 summarizes the specifications for categories 1 to 6 UTP. It is important to note that a higher category of cable can be used for applications that require a lower cable category.

UTP Category	Maximum Data Speed	Attenuation /NEXT limit	Applications
Cat 1 UTP	< 1Mbps		Telephone lines
Cat 2 UTP	4 Mbps	4 MHz	4 Mbps token ring over UTP
Cat 3 UTP	16 Mbps	16 MHz	10BaseT Ethernet. Tested for attenuation and near-end crosstalk up to 16 MHz.
Cat 4 UTP	20 Mbps	20 MHz	16 Mbps token ring over UTP. Tested for attenuation and near-end crosstalk up to 20 MHz.
Cat 5 UTP	100 Mbps (2 pair) 1 Gbps (4 pair)	100 MHz	100BaseT (fast) Ethernet, 155 Mbps ATM, gigabit Ethernet
Cat 5e UTP	100 Mbps (2 pair) 1 Gbps (4 pair)	100 MHz	100BaseT (fast) Ethernet, 155 Mbps ATM, gigabit Ethernet Category 5e cable has a tighter quality control standard than standard cat 5 cable.
Cat 6 UTP	2.5 Gbps (2 pair) potentially up to 10 Gbps (4 pair)	200 MHz	None that <b>require</b> cat 6 at the time of this writing. The IEEE is working on a copper 10 Gbps Ethernet standard that would require cat 6 if released.

**Figure 3-1** Unshielded Twisted Pair Specifications

Wire thickness is measured by gauge and represented with the unit **AWG** (American Wire Gauge). The higher the gauge number, the thinner the wire. UTP wiring of different categories must meet specifications for resistance to different forces that interfere with signal strength. Two of the more common sources of interference or loss of signal strength are as follows:

- **Attenuation** is the decrease in the power of signal over a distance in a particular type of wire or media.
- **Near-End Crosstalk (NExT)** is signal interference caused by a strong signal on one-pair (transmitting) overpowering a weaker signal on an adjacent pair (receiving). Near End Crosstalk and Attenuation to Crosstalk Ratio (ACR) are both measured in dB or decibels. A decibel is a logarithmic rather than linear measurement of the ratio between two powers, often a data signal and some type of noise or interference.



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### BEYOND CAT 6

Although no official category 7 cable has become standardized, media vendors are attempting to develop cable that is capable of carrying data at frequencies of up to 600 MHz. Some such attempts are not truly unshielded twisted pair but rather are FTP or foil-twisted-pair cable that is more closely related to shielded twisted pair. Buyers must be wary of so-called category 7 cable by focusing on whether the cable is truly UTP and whether it is a specified EIA/TIA standard.

Anixter, a major cabling manufacturer, has proposed a program to define performance characteristics for cabling tested beyond the 100 MHz required for cat 5. Since higher-speed network architectures such as fast Ethernet and gigabit Ethernet require four pair of UTP to be transmitting power simultaneously, it was determined

Level	Highest Test Frequency	Required Frequency in MHz for Attenuation to Crosstalk Ratio (ACR) at 10dB (Powersum Bandwidth)
5	200 MHz	80 MHz
6	350 MHz	100 MHz
7	400 MHz	160 MHz

**Figure 3-2** UTP Level 5, 6, and 7 Performance Specifications

that crosstalk should be measured by taking into account the crosstalk influence from all pairs in the cable (whether 4-pair or 25-pair) rather than just crosstalk between adjacent pairs, or pair-to-pair, as had been required for cat 5 certification. This type of crosstalk test is called **Powersum Crosstalk**. Key performance specifications for Level 5, 6, 7 are detailed in Figure 3-2.

Regardless of the final standard for category 7 cable, it is likely that the standard will not support the venerable RJ-45 connector. The design of the RJ-45 simply promotes too much crosstalk to effectively support the higher data speeds associated with category 7. However, changing the cable could spell the end of the category 7 project. If the connector changes, then it would not be possible to use category 7 cable and connectors with existing data communication technologies such as fast and gigabit Ethernet. Without this backward compatibility, many buyers might simply choose to migrate their cable plants directly to fiber-optic cable to take advantage of its even higher bandwidth.



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### COMMON UTP INSTALLATION MISTAKES

Strict adherence to EIA/TIA 568 installation standards is essential to successful transmission at 100 Mbps or higher over UTP cabling. Because a less-than-perfect installation will probably transport 10 Mbps traffic without any problem, issues with noncompliant installations may not surface until upgrades to higher-speed network architectures are attempted. The most common installation mistakes are:

- Untwisting the UTP wire more than the maximum 13 mm in order to secure the UTP to wall plates or punch-down blocks. Exceeding the maximum bend radius specified for UTP. Overbending the wire increases crosstalk between stretched pairs of wires.
- Bundling the groups of UTP together too tightly with cable ties. Excessively pinching the UTP together increases crosstalk between pairs.

### STP-Shielded Twisted Pair

Data transmission characteristics, and therefore the data transmission speed, can be improved by adding **shielding** around each individual pair and the entire group of twisted pairs. This shielding may be a metallic foil or copper braid. The function of the shield is simple. It “shields” the individual twisted pairs as well as the entire cable from either EMI (Electromagnetic Interference) or RFI (Radio Frequency Interference). However, installation of shielded twisted pair can be tricky.

The shielding is metal and therefore a conductor. Often, the shielding is terminated in a drain wire that must be properly grounded on one end of the cable. It is critical that the shield be grounded on only one end or a *ground loop* can occur. In a ground loop a small current flows across the shield from the ground connector at one end of the cable to the ground connector at the other end of the cable. This current can actually decrease performance by inducing noise directly into the signal wires—quite the opposite of why the shielding was added.

Shielded twisted pair is becoming much less common. STP was commonly specified for token ring installations. However, recent technologies such as high-speed Ethernet, ATM, and other high-speed network architectures have specified category 5+ UTP rather than STP.

## Coaxial Cable

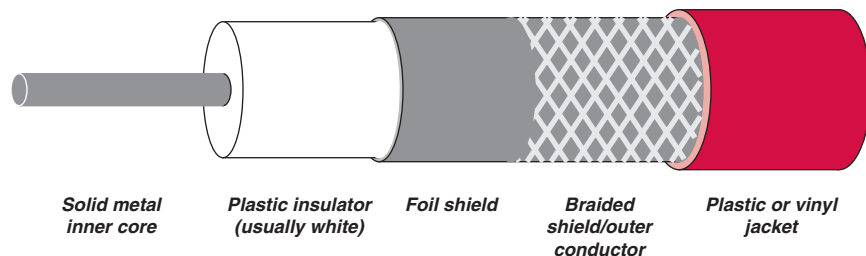
Coaxial cable, more commonly known as **coax** or cable TV cable, has specialized insulators and shielding separating two conductors, allowing reliable, high-speed data transmission over relatively long distances. Figure 3-3 illustrates a cross-section of a typical coaxial cable. Coax comes in various thicknesses and has been historically used in Ethernet network architectures. In some cases, these network architecture specifications include required characteristics of the (physical layer) coaxial cable over which the (data-link layer) MAC layer protocol is transmitted.

Modern local area network implementations rarely use coaxial cable. However, coaxial cable is still a key component of the cable television system. With the advent of cable modems and the use of the cable television system as a mechanism to provide high-speed Internet connectivity to homes coaxial cable continues to play an important role in data communication.

## Fiber-Optic Cable

Fiber-optic cable is the current reliability and performance champion of the data communication world. Although the most expensive media choice currently available, fiber-optic media delivers data transmission speeds measured in gigabytes (billions of characters) per second over distances often measured in miles.

Fiber-optic cable is also one of the most secure of all media, as it is relatively untappable, transmitting only pulses of light, unlike all of the aforementioned media, which transmit varying levels of electrical pulses. Because fiber optic is really a thin



**Figure 3-3** Coax Cable: Cross-Section

fiber of glass, it is immune to electro-magnetic interference, contributing to its high bandwidth and data transmission capabilities. Another important thing to remember is that fiber-optic cable requires more careful handling than copper media. Figure 3-4 illustrates a cross-section of a fiber-optic cable.

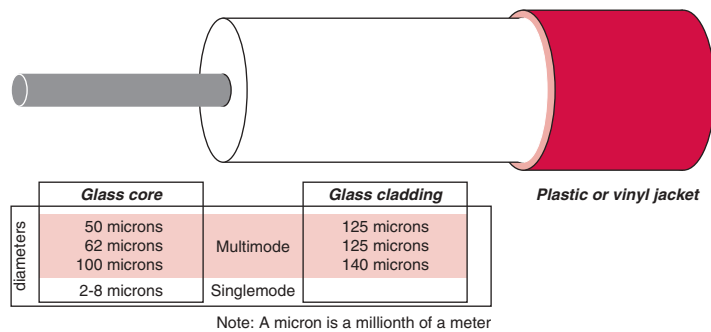
**Light Transmission Modes** Once a pulse of light enters the core of the fiber-optic cable, it will behave differently, depending on the physical characteristics of the core and cladding of the fiber-optic cable. In a **Multimode** or **Multimode Step Index** fiber-optic cable, the rays of light will bounce off of the cladding at different angles and continue down the core while others will be absorbed in the cladding. These multiple rays at varying angles cause distortion and limit the overall transmission capabilities of the fiber. This type of fiber-optic cable is capable of high bandwidth transmission but usually over fairly short distances.

By gradually decreasing a characteristic of the core known as the refractive index from the center to the outer edge, reflected rays are focused along the core more efficiently yielding higher bandwidth over several kilometers. This type of fiber-optic cable is known as **Multimode Graded Index Fiber**.

The third type of fiber-optic cable seeks to focus the rays of light even further so that only a single wavelength can pass through at a time, in a fiber type known as **single mode**. Without numerous reflections of rays at multiple angles, distortion is eliminated and bandwidth is maximized. Single mode is the most expensive fiber-optic cable, but can be used over the longest distances.

**Core Thickness** The thickness of fiber-optic cable's *core* and *cladding* is measured in microns (millionths of an inch). The three major core thicknesses are 50, 62, and 100 microns with their associated claddings being 125, 125, and 140 microns, respectively. The increasing core thicknesses generally allow transmission over longer distances at a greater expense, however.

**Light Source Wavelength** The wavelength of the light that is pulsed onto the fiber-optic cable is measured in nanometers (nm), with the optimal light transmitting wavelengths coming in three distinct windows of 820 nm, 1,310 nm, and 1,500 nm; 820nm and 1,310nm are most often used for local and campus-wide networking such as gigabit Ethernet, while 1,310nm and 1,500nm are used by carriers to deliver high bandwidth fiber-based service over long distances. The higher-frequency light-emitting sources carry a higher price tag.



**Figure 3-4** Fiber-Optic Cable: Cross-Section



Media Type	Also Called	Bandwidth	Distance Limits	Connectors	Comments/Applications	Architectures			
						Ethernet	Fast Ethernet	Gigabit Ethernet	ATM
4-wire phone station wire	Quad RYGB	3 Kbps	200 feet	RJ-11 jacks	4 insulated wired-red, green, yellow, black. Home phone wiring. Voice Applications				
Flat gray modular	Flat satin, telephone cable, silver satin	14.4 Kbps	10-20 feet	RJ-11 or RJ-45 plugs	Comes with 4,6,8 conductors. Used for short data cables using modular (mod-tap) adapters	■			
Unshielded twisted pair	UTP	100 Mbps	100 feet	RJ-45	5 Designated categories. Twists prevent interference, increase bandwidth. Voice grade usually not suitable for data	■	■	■	■
Shielded twisted pair	STP	16 Mbps	100 feet	RJ-45 or IBM data connectors	Shielding reduces interference but complicates installation	■	■		■
Coax- thick	Frozen yellow garden hose	10 Mbps	500 feet	AUI (attachment unit interface)	Original Ethernet cabling	■			
Coax-thin	RG-58, thinnet, cheapernet	10 Mbps	200 feet	BNC connector	Looks like cable TV cable. Easier to work with than thick coax.	■			
Coax-thin	RG-62	2.5 Mbps	200 feet	BNC or IBM data connector	Similar to RG-58 (thinnet) but different electrical characteristics make these cables NOT interchangeable				
Fiber-optic cable	Fiber Glass	several Gbps	several kilometers	SI or SMA 905 or SMA 906	Difficult to install but technology is improving. High bandwidth, long distance, virtually error free, high security	■		■	■

Figure 3-5 LAN Media Technology Analysis

### POINT-TO-POINT DATA TRANSMISSION TECHNOLOGIES

The most basic data communication technologies are those used to directly connect two devices. These connections can be used to connect a computer to peripheral devices such as modems, scanners, PDAs, and so on, or as the basis for a directly connected computer-to-computer data connection. Operating at layer one of the OSI Network Reference Model, these technologies provide a physical connection that can be used to carry many higher-level protocols.

### Serial Transmission Standards

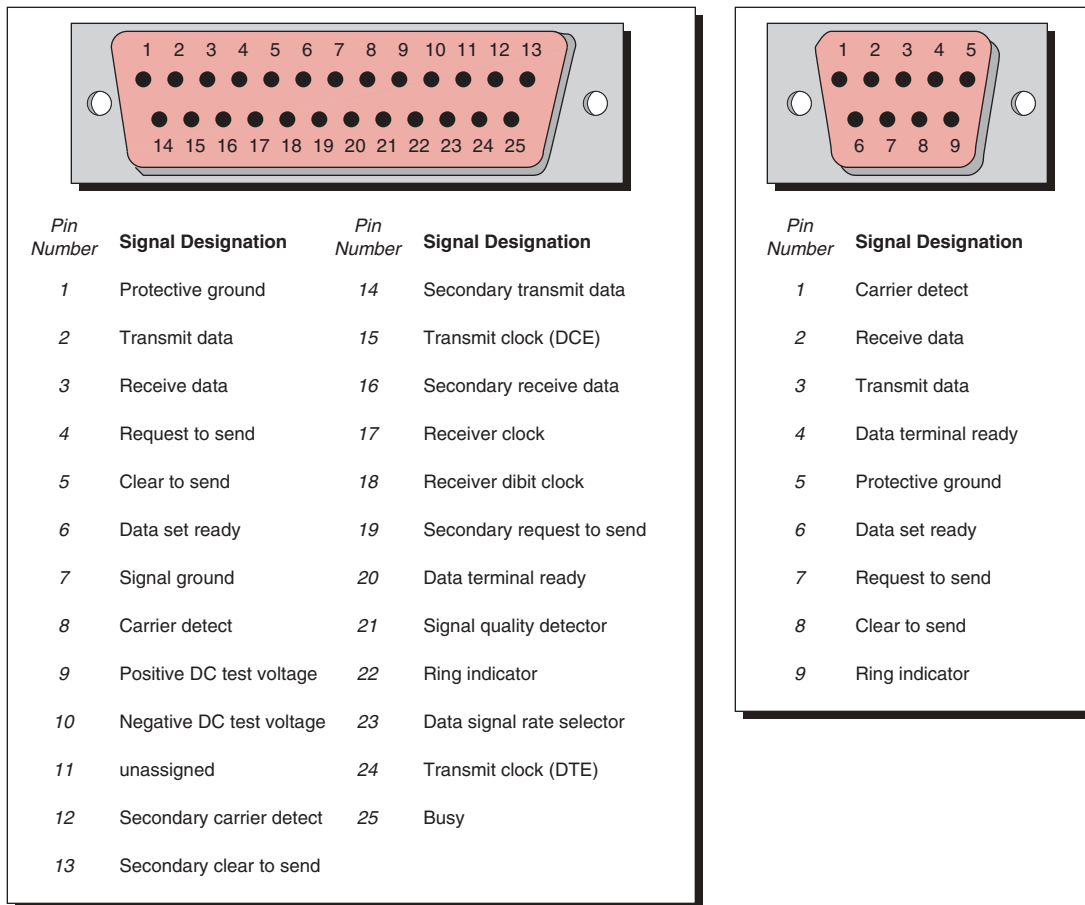
Serial transmission is the basis of most data communication between computers. There are several different serial communication standards available for use in modern computers, including RS-232, USB, and IEEE 1394 (Firewire).

**RS-232** RS-232 is currently the most commonly used serial standard for modem communication. Standardized by the Electronics Industries Association (EIA), RS-232 is currently in its third release (RS-232-C). The prevalence of RS-232 in the PC marketplace is so great that the term serial port has come to mean an RS-232 serial connection. Although newer serial standards threaten to replace RS-232 as the predominate serial standard in the not too distant future, it still merits a close inspection.

RS-232 uses electrical signals to transmit the ones and zeroes of the digital datastream. The RS-232 standard defines voltages of between +5 and +15 volts DC on a given pin to represent a logical zero, otherwise known as a space, and voltages of between 5 and 15 volts DC to represent logical ones, otherwise known as a *mark*.

RS-232 can be implemented on a multitude of data connectors. In the case of the DB-25 connector illustrated in Figure 3-6, the presence or absence of an electrical charge on each of these 25 pins has been designated as having a specific meaning in data communications. These standard definitions are officially known as **RS-232-C**. They were issued by the Electronics Industries Association (EIA), and are listed in Figure 3-8.

Although all 25 pins are defined, in most cases, 10 or fewer of the pins are actually used in the majority of serial transmission applications. On some PCs, such as



**Figure 3-6** RS-232 Serial Transmission Protocol as Defined for DB-25 and DB-9 Connectors

personal computers as well as many notebook and laptop computers, the serial port has only 9 pins (DB-9 connector) and the RS-232 serial transmission protocol is supported as listed in Figure 3-6. Other RS-232 implementations rely on mini-DIN connectors or phono-plug style connectors. Pictures of common RS-232 connectors are shown in Figure 3-7.



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### PHYSICAL INTERFACES VS. TRANSMISSION PROTOCOLS

It is important to distinguish between those standards that describe the connectors or physical interfaces that are used to connect appropriate cables to a computer's physical ports, and the standards that describe the electrical characteristics, or transmission protocols used.

**RS-232 Cables** To connect devices via RS-232, a multi-wire cable must be used. The cable has several small, insulated wires within an outer jacket. Each signal to be carried, or RS-232 pin to be supported, requires its own individual inner wire.

The number of signals that must be transmitted across an RS-232 connection between two devices will depend on the software used. The number of signals required can vary from as few as 2 for one-way communication to 12 for a full-duplex modem connection. Figure 3-8 summarizes the signals that are most commonly included in modem cables and designates which signals are assigned to which pins on both DB-9 and DB-25 connectors. The signals are arranged in logical pairs in order to increase understanding rather than in order of pin number.

**DCE vs. DTE** The original application of RS-232 was to connect computing devices to modems. To make cabling this “standard” solution easier, two classifications of RS-232 devices were created. The pin-outs for these classifications were established so that the cable could be “straight through” in nature, where each pin is connected to the same pin on the other end of the cable. Pin 1 will connect to pin 1, pin 2 to pin 2, and so on. The PC and the modem in our scenario are examples of these two classifications: **DTE (data terminal equipment)** and **DCE (data communications equipment)**, respectively. DCE can also be expanded as **data circuit terminating equipment**.

Although this approach made sense for modem applications, the use of RS-232 has expanded to include all sorts of electronic equipment ranging from modems to personal digital assistants (PDAs) to advanced television remote controls. It is therefore critical to establish exactly which signals are associated with each pin on the connector. It is impossible to rely on any standard mapping, as each device might have deviated from the loosely enforced standard if they even use a “standard” connector.



DB-25 connector (female)



DB-9 connector (female)

**Figure 3-7** Common RS-232 Connectors

RS-232 Signal	DB-25 Pin	DB-9 Pin	Abbr.	From	To	Explanation
Protective Ground	1	5	PG			A reference voltage used to protect circuit boards inside PC
Signal Ground	7	5	SG			A reference voltage used to determine proper signal voltage for ones and zeroes
Transmit Data	2	3	TXD	DTE	DCE	Discrete voltages representing characters encoded as 1s and 0s are transmitted on this pin to deliver the actual data message
Receive Data	3	2	RXD	DCE	DTE	Discrete voltages representing characters encoded as ones and zeroes are received on this pin to receive the actual data message
Request to Send	4	7	RTS	DTE	DCE	Used in conjunction with CTS to perform modem-to-modem flow control allowing modems to take turns transmitting to each other.
Clear to Send	5	8	CTS	DCE	DTE	Used in conjunction with RTS to perform modem-to-modem flow control allowing modems to take turns transmitting to each other
Data Set Ready	6	6	DSR	DCE	DTE	Used for initial handshaking between local modem and local PC to indicate local modem is functional
Data Terminal Ready	20	4	DTR	DTE	DCE	Used for initial handshaking between local modem and local PC to indicate local PC is functional
Transmit Clock	15		TC	DTE	DCE	Clocking signal transmitted on this pin. Required for synchronous modems only.
Receive Clock	17		RC	DCE	DTE	Clocking signal received on this pin. Required for synchronous modems only.
Carrier Detect	8	1	CD	DCE	DTE	Indicates that the local modem has successfully contacted the remote modem and is ready to transmit data
Ring Indicator	22	9	RI	DCE	DTE	Indicates to the local modem that a call is incoming and that the modem should auto-answer the call.

**Figure 3-8** Most Commonly Used RS-232 Signals

**Serial/Parallel Conversion: UARTs** Data travel via parallel transmission within a PC over the PC's main data bus. The data emerging from the serial port must be in serial format. Therefore, somewhere inside the PC a parallel to serial conversion must be taking place. A specialized computer chip known as a **UART (Universal Asynchronous Receiver Transmitter)** acts as the interface between the parallel transmission of the computer bus and the serial transmission of the serial port. UARTs differ in performance capabilities based on the amount of on-chip buffer memory. The commonly used 16550 UART chip contains a 16 byte on-chip buffer memory for improved serial/parallel conversion performance.



Standard Name	Standards Body	Physical Interface Connector	Description
RS-422	EIA	DB9 DB25 DB37	An electrical specification usually associated with RS-449 (DB37 Connector). Each signal pin has its own ground line (balanced) rather than sharing a common ground. Up to 10Mbps over 1,200 meters. Use of DB25 or DB9 is also possible.
RS-423	EIA	DB9 DB25 DB37	An electrical specification is usually associated with RS-449 (DB37 Connector). Signal pins share a common ground wire. (Unbalanced signaling) Up to 10 Mbps over 1,200 meters. Use of DB25 or DB9 is also possible.
RS-449	EIA	DB37 plus DB9	A physical/mechanical specification for a DB-37 (37-pin connector), plus an additional DB-9 if required. Usually associated with either RS-422 or RS-423 electrical specifications.
RS-485	EIA	DB9 DB25 DB37	Can be used in multipoint applications in which one computer controls multiple (up to 64) devices. Often used in computer-integrated manufacturing operations or in telecommunications management networks.
RS-530	EIA	DB25	A physical/mechanical specification that works with RS-422 or RS-423 over a DB-25 connector rather than a DB-37 connector. Allows speeds of up to 2 Mbps.
V.35	ITU	M-Block	An international standard for serial transmission up to 48 Kbps defined for an M-block connector. Often used on data communications equipment that must interface to high-speed carrier services.

**Figure 3-9** Other Traditional Serial Transmission Standards

### OTHER TRADITIONAL SERIAL TRANSMISSION STANDARDS

RS-232 is officially limited to 20 Kbps (kilobits per second) for a maximum distance of 50 feet. In reality, depending on the type of media used and the amount of external interference present—RS-232 can be transmitted at higher speeds and/or over greater distances. However, modern hardware typically supports speeds up to 115 Kbps using 16550 family UARTS.

To resolve the speed and distance limitations of RS-232, several other serial transmission standards have been developed. Some of these standards also include the ability to connect more than two devices at the same time. A serial standard that can connect three or more devices together concurrently is known as a multipoint serial communications standard. A list of common serial standards is provided in Figure 3-9.

**Universal Serial Bus (USB)** Although RS-232 is historically the most widely implemented serial standard, a new standard serial communication standard has virtually replaced RS-232 in all but the most basic applications. This is because three basic architectural limitations in the RS-232 technology limit its application to new devices such as scanners, digital cameras, video cameras, and personal digital assistants: RS-232 is

slow (only up to 115 Kbps), only supports one device per port, and requires significant configuration to attach a device.

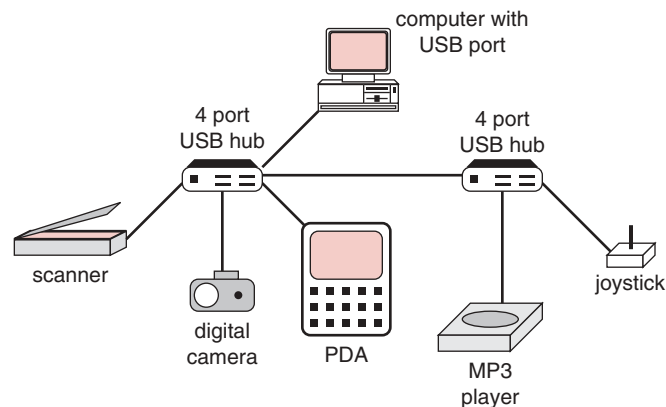
The **universal serial bus (USB)** is a high-speed, multipoint serial communications technology developed by the USB Implementer's Forum to resolve RS-232's shortcomings. There are two versions of USB currently available—the original USB 1.1 specification and a newer, higher-speed USB 2.0 specification. USB 2.0 is backward compatible with USB 1.1. However, to gain the higher speeds offered by USB 2.0, devices must be attached either directly to the computer or to a USB 2.0 compatible hub.

USB version 1.1 operates at either 1.5 Mbps or 12 Mbps. That equates to more than 1,000 times the maximum speed of RS-232. USB 2.0 can operate at even higher speeds, up to 480 Mbps. This increased speed is significantly important when supporting such high data devices as scanners and digital cameras. As covered in chapter 4, it is even possible to connect to a local area network (LAN) via a USB network interface card (NIC).

Both USB 1.1 and USB 2.0 use electrical signals to transmit the ones and zeroes of the digital datastream. Unlike RS-232, which is ground referenced (uses voltages of +5Vdc and 0Vdc for ones and zeroes), USB uses a differential electrical signal. A digital 1 is represented when D+ signal line voltage is 200 mv greater than the D- signal voltage. Similarly, a digital 0 is represented by the D+ signal voltage being 200 mV less than the D- signal voltage. Differential signaling offers more noise resistance than ground referenced signaling while greatly reducing the potential impact of ground loops.

When connected to a computer, low-speed USB devices such as joysticks and PDAs create virtual serial ports. These ports are typically assigned as if they were physical RS-232 com ports (COM2, COM3, etc.) Since each of these ports can only use up to 115 Kbps of bandwidth, they can easily be multiplexed over the same physical USB connection with no loss of performance. However for high-speed devices such as scanners and video cameras, it is better to connect them to one of the computer's USB ports.

USB can support up to 126 devices on each port. Some devices come with two USB ports so that the user can simply "daisy-chain" the devices together. Although this solution is functional for a couple of devices, a better solution for larger implementations is to use a USB hub. As illustrated in Figure 3-10, a USB hub is a device that connects directly to the computer's USB port and offers multiple ports to connect other USB devices.



**Figure 3-10** USB Hub Implementations

To reduce the configuration hassles traditionally associated with serial connectivity using RS-232, USB is designed to be *plug and play*. Devices are automatically given an address, assigned a speed, and identified by the computer's operating system. As long as the operating system supports USB plug and play all that is required to connect a device is to plug it into either the computer or to a USB hub connected to the computer.

To make the process of attaching devices even easier, the USB ports and cables also include the power to the device, eliminating the need to have a separate power supply for each peripheral. When using powered USB devices it is important that the power consumption of the attached devices does not exceed that of the computer port or USB hub to which the devices are attached. While the USB specification requires 500 milliamps of power, in an effort to save battery life some notebook computer vendors have reduced the USB power output to lower levels. In these cases, some combinations of devices may not work without adding an externally powered USB hub.

There are two connector types associated with USB. The USB "A" connector is used to connect to computers and the USB "B" connector is used to connect to the devices. The ability to disconnect the USB cable at the device end of the connection makes it significantly easier to change devices compared to having to reach behind the computer to disconnect the cables. Figure 3-11 shows the USB A and B connectors.

**IEEE-1394/Firewire** Another high-speed serial standard is **IEEE 1394**. Originally developed by Texas Instruments and implemented by Apple Computer Inc. as the proprietary **Firewire**, the interface was standardized by the IEEE in 1995. Sony has trademarked the name **i.Link** for their implementation of IEEE-1394, and that moniker seems to be gaining popularity, at least among Japanese consumer electronics manufacturers.

Similar to USB, IEEE-1394 is a multipoint serial bus-based solution. Devices can be added or removed from the live bus. Devices can be daisy chained or connected to an IEEE-1394 hub for connectivity between more than two devices. Although similar to USB in many ways, IEEE-1394 is not intended to directly compete with USB but rather to complement USB. USB offers a low- to medium-speed serial solution while IEEE-1394 offers a high-speed solution. By having two separate serial standards, each can be optimized for specific applications.

IEEE-1394 uses electrical signals to transmit the ones and zeroes of the digital datastream. Like USB, IEEE-1394 uses differential signaling to provide better performance and noise abatement over longer distances. Unlike USB IEEE-1394b is also capable of operating over fiber-optic media, offering higher speeds and greatly increased distances.



USB-A (on left) and USB-B (on right) connectors

**Figure 3-11** USB Connectors

IEEE-1394 is a high-speed serial solution ranging in speed from 400 Mbps (original specification) to 800 Mbps (1394b). One of the key differentiators between IEEE-1394 and other serial bus standards is that, in addition to standard asynchronous communication, IEEE-1394 includes support for isochronous communication. *Isochronous communication* guarantees data delivery at a constant, predetermined rate. This allows IEEE-1394 to be used in time critical multimedia solutions. The constant data delivery rate reduces the need to buffer data, thereby greatly reducing the cost of implementing the technology compared to a traditional asynchronous solution.

Taking advantage of its isochronous capabilities, the main applications of IEEE-1394 at the current time are in the transmission of digital data between consumer electronics devices. IEEE-1394 has been adopted by the digital VCR Manufacturers Association as its standard interconnection technology. The ongoing conversion of television from an analog format to digital HDTV technologies will increase the marketplace for IEEE-1394 technologies in the consumer electronics marketplace.

IEEE-1394 ports are also being introduced in multimedia-capable computers. In addition to allowing the computer to connect to digital camcorders and VCRs, IEEE-1394 ports will allow data network solutions to be deployed. To support the use of IEEE-1394 on computer platforms, the IEEE-1394 Trade Association released an updated version of the standard known as IEEE-1394b in 2002. The IEEE-1394b standard increases speeds to 800 Mbps at 100 meters and reduces latency by streamlining the protocol. Also known as Firewire 800, IEEE-1394b is designed to be backward compatible with the original IEEE-1394 standard.

IEEE 1394 uses two different connectors: a four-wire connector that supports full-duplex data transmission and a six-wire connector that also provides power to a connected device. Figure 3-12 shows these two interface connectors.

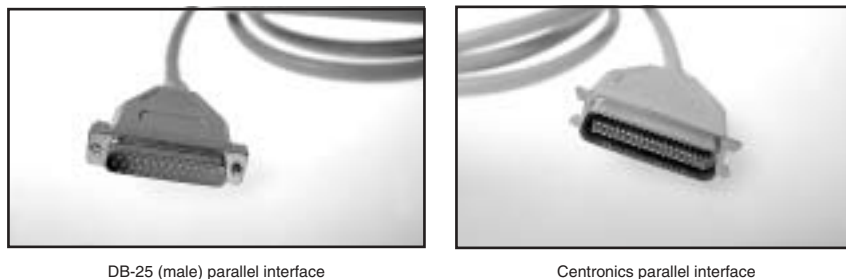
## Parallel Transmission

Parallel transmission is primarily limited to transmission of data within a computer, although the release of the IBM personal computer included an 8-bit parallel interface designed to connect the computer to a printer. Common physical interfaces associated with this parallel transmission technology are the DB-25 connector and the Centronics connector. The Centronics connector is a 36-pin parallel interface. In addition to the physical plug and socket, the Centronics parallel standard defines electrical signaling for parallel transmission and is a de-facto standard. DB-25 and Centronics parallel physical interfaces are illustrated in Figure 3-13.



IEEE-1394 Connectors

**Figure 3-12** IEEE-1394 Connectors



**Figure 3-13** Parallel Transmission Physical Interfaces

Initially intended for connecting a printer, the parallel port on personal computers later saw duty as a means of connecting medium-speed peripheral devices such as scanners, tape drives, and video cameras due to its relatively high speed as compared to RS-232. However, with the proliferation of USB and IEEE 1394, use of the Centronics parallel port has significantly trailed off to the point that some notebook computer vendors are no longer including parallel ports on their products.

## Wireless Technologies

One of the largest hassles with the explosion of modern computing devices is the series of cables required to connect them. This is even more of a problem when traveling. If you have a notebook computer, a PDA, a cell phone, and an MP3 player, you could potentially need three different data cables to connect them, in addition to the requisite power supplies and cords. Two technologies have been developed as wireless cable replacements: Infrared (IRDA) and radio (Bluetooth).

**Infrared (IrDA)** The Infrared Data Association (**IrDA**) is an international standards body responsible for creating standards that apply to the use of infrared (Ir) light to provide wireless connectivity for devices and/or to locations that would typically require more traditional wire-based solutions. IrDA signals are point-to-point nature, have a narrow angle (30 degree cone), are limited to around meter, and have a throughput of 9,600 bps to 4 Mbps. IrDA has proven to be a popular technology, with compliant ports currently available in an array of devices, including embedded devices, pagers, phones, modems, cameras, watches, computers (PCs) and laptops, PDAs, printers, and other computer peripherals.

There are two widespread IrDA versions: IrDA 1.0 and 1.1. Designed as a direct RS-232 serial port replacement, IrDA 1.0 (also known as SIR) offers data speeds of 9.6, 19.2, 38.4, 57.6, and 115.2 Kbps. IrDA 1.1 (FIR) increases the list of available speeds to include 576 Kbps, as well as 1.152 and 4.0 Mbps. A third version of the standard (FIR) that supports data speeds up to 16 Mbps was ratified but has not seen widespread use. Regardless of version, IrDA ports are addressed as RS-232 serial ports.

Despite widespread acceptance, infrared has some significant limitations to its use. In general, IrDA is a point-to-point protocol; only two devices can communicate at any given time. If a session is live between two devices and a third device attempts to initiate a session, the initial session will be dropped. There is a derivative of IrDA that supports multi-point communication (IrLAN), but it has not achieved widespread adoption and probably will not due to the evolution of Bluetooth technologies.

Another key limitation of IrDA is that there must be a direct line of sight between the two communicating devices. If either is moved, the communication session will be dropped. This limitation effectively prevents IrDA from being used in many applications such as connecting a PDA to the Internet through a cell phone in a belt holster. Using IrDA, the phone must be out on a table right in front of the PDA. Between these limitations and the limited speed available, IrDA is likely to be replaced by Bluetooth as that standard matures.

**Bluetooth** Bluetooth is the name given to an emerging wireless radio frequency (RF) communication standard. Originally developed by Erickson, Bluetooth is currently backed by Bluetooth Special Interest Group (SIG), a collection of Bluetooth promoters that includes 3COM, IBM, Intel, Microsoft, and Nokia, among others, with the purpose of developing and promoting the use of the Bluetooth technology.

Bluetooth uses radio frequency communication in the unlicensed 2.4-2.4835 GHz band using *frequency hop spread spectrum* (FHSS). As its name suggests, FHSS hops from one frequency to another throughout the allowable frequency range. The pattern of frequency hopping must be known by the wireless receiver so that the message can be reconstructed correctly. A given wireless transceiver's signal is on a given frequency for less than 1 second. By constantly changing frequency, the transmission tends to be less affected by interference, an especially desirable characteristic for mobile computing applications.

Bluetooth offers data speeds of up to 1 Mbps up to 10 meters. Unlike IrDA, Bluetooth supports a LAN-like mode where multiple devices can interact with each other. Due to the limited size of the Bluetooth coverage area, the terms *piconet* and *personal area network* (PAN) have been coined to describe a Bluetooth coverage zone.

The key limitations of Bluetooth are security and interference with wireless LANs. The fact that Bluetooth doesn't require line-of-sight to communicate cuts both ways: while it makes it possible to use your PDA with your cellular phone that is stashed in your briefcase, it also makes it possible for someone else with a device hidden from view to attempt to gain illicit access to your computing devices. Bluetooth attempts to mitigate this risk through the use of strong authentication and encryption technologies. Because Bluetooth uses the same frequency range as IEEE 802.11b wireless networks, simultaneous use of both technologies greatly affects performance. This concept is covered further in chapter 4.

Devices hitting the market that include Bluetooth include cellular phones, PDAs, headphones, and mobile gaming platforms. Although the technology is too new to guarantee widespread success, it shows great promise as a way to eliminate the spaghetti bowl of cords that beleaguers mobile workers.

## ■ INTERNET ACCESS TECHNOLOGIES

After connecting to peripheral devices, most people want to connect their computer to the Internet. While a technical discussion of the Internet is beyond the scope of this chapter, suffice it to say that it is a large, international network that offers a wide-ranging selection of data services to any connected computer including e-mail, instant messaging, Web pages, and streaming media. More detail on the technical "how" of the Internet will be provided in chapters 7 and 8.

The process of connecting to the Internet is conceptually straightforward: All you have to do is create a link between your computer and a device connected to the

Internet. The traffic from the local computer that needs to go to the Internet will be sent across this link. The problem is the distance between the local computer and the Internet-connected device.

Although the point-to-point data communications technologies previously discussed provide a means to connect a computer to a local device or even another computer located in close physical proximity, they are not capable of dealing with the distance between the local computer and the remote Internet connection device. A whole new class of data communication technologies is required to meet the distance and speed requirements for Internet access. The Internet access architecture is illustrated in Figure 3-14.

## Internet Service Providers

In most cases, an individual wishing to connect to the Internet will initiate a link to a company whose business is extending the Internet to individuals. These companies, known as **Internet service providers (ISPs)**, take a high-speed connection to the Internet and—using a collection of Internet access technologies—offer Internet connectivity to individual users.

ISPs range in size from a local provider that focuses on meeting the needs of a geographically limited area to national and international providers such as America Online (AOL), which provide service across large geographic areas. In addition to the area they service, ISPs vary widely in the access technologies offered, data speeds provided, and pricing methods.



### SELECTING AN ISP

Regardless of size, ISPs all provide access to the same Internet. When selecting an ISP it is important to look at four key criteria:

- *Service hosting*—Do you need the ISP to host your Web pages, e-mail addresses, and so on?
- *Performance*—What types of access technologies does the ISP support? What data rates are offered? What is the confirmed information rate (CIR—the

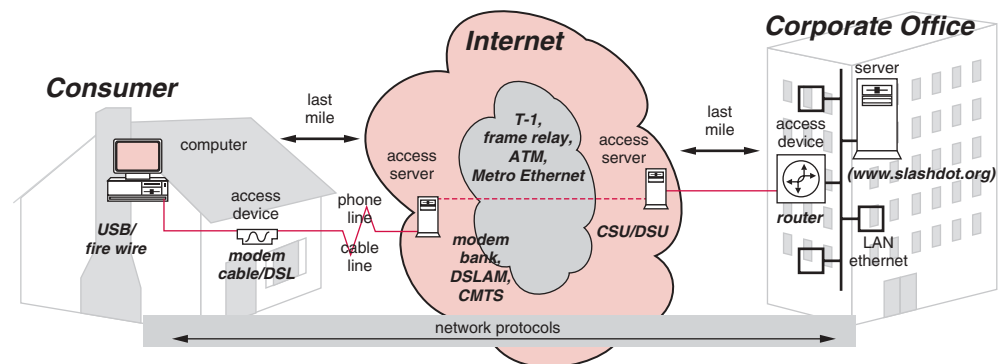


Figure 3-14 Internet Access Architecture

amount of throughput the ISP guarantees, which is usually significantly slower than the base speed)?

- *Cost*—What is the monthly cost of the service? What is the cost per megabyte per second? Are there service caps after which surcharges apply?
- *Reliability*—Does the ISP have a generator on site to maintain connectivity in the event of a power failure? Does the ISP have multiple links to the Internet so that if one fails you still have access? Does the ISP offer multiple links to your location to protect from the failure of a single link?

## Dial-Up Modems

The first and most basic method for connecting a home computer to the Internet is to use a dial-up modem. A dial-up modem creates a circuit-switched connection across the public switched telephone system (PSTN) to another modem that is connected to the Internet.

**Architecture** A switched or **dial-up** line is the type of phone line typically installed in a home or place of business. To place a call, you pick up the receiver or handset, wait for a dial tone, and dial the number of the location you wish to call. This ordinary type of phone service is sometimes called **POTS** or **Plain Old Telephone Service**. More formally, the phone network is referred to as the **Public Switched Telephone Network (PSTN)**. Figure 3-15 illustrates the major components of the PSTN.

As introduced in chapter 1 and detailed in chapter 5, the phone set is connected to a large switch in a telephone company building called a central office or CO via a local loop. When a call is dialed, the telephone switch connects the phone set to the destination set by finding an available circuit or path.

**Technology** Calls placed over dial-up lines through CO switches that have connections built from available circuits are called **circuit-switched connections**. In order to interface transparently to the PSTN, modems must be able to dial and answer phone calls to and from other modems.

The next important characteristic related to transmitting data over a dial-up phone line has to do with how the data are represented on that phone line. First, it is

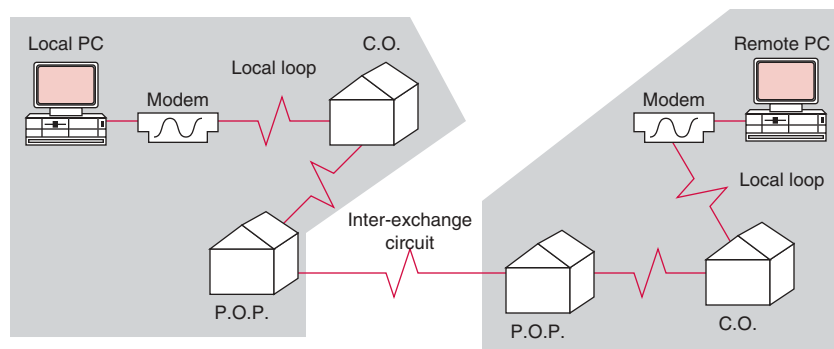


Figure 3-15 PSTN Architecture

important to realize that today's dial-up phone network was originally designed to carry voice conversations efficiently and with reasonable sound quality. This "efficiency of design with reasonable sound quality" meant reproducing a range of the frequencies of human speech and hearing just wide enough to produce reasonable sound quality. That range of frequencies, or **bandwidth**, is 3,100 Hz (From 300 Hz to 3,400 Hz), and is the standard bandwidth of today's voice-grade dial up circuits (phone lines). Hz is the abbreviation for hertz. One hertz is one cycle per second. The higher the number of hertz or cycles per second, the higher the frequency. Frequency, wavelength, hertz, and cycles per second were introduced in chapter 2.

This 3,100 Hz is all the bandwidth with which the modem operating over a dial-up circuit has to work. Because the dial-up phone network was designed to be able to mimic the constantly varying tones or frequencies that characterize human speech, only these continuous, wave-like tones or frequencies can travel over the dial-up phone network in this limited bandwidth.

The challenge for the modem is to represent the discrete, digitized ones and zeroes from the input (PC) side of the modem in a continuous or analog form within a limited bandwidth so that the data may be transmitted over the dial-up network. Figure 3-16 summarizes the results of I-P-O analysis involving modems and the PSTN.

The modem's job is to convert digital data into analog data for transmission over the dial-up phone network and to convert analog data received from the dial-up network into digital data for the terminal or PC. As previously discussed in chapter 2, the proper names for these processes are *modulation* and *demodulation*. In fact, the word *modem* is actually a contraction for Modulator/demodulator.

Most local loops that are used for connection to the PSTN to supply switched, dial-up phone service are physically described as *two-wire circuits*. Since one of these two wires serves as a ground wire for the circuit, that leaves only one wire between the two ends of the circuit for data signaling. Dial-up or switched two-wire circuits generate a dial tone.

Given that two-wire dial-up circuits only have one wire for data signaling, only one modem could be transmitting at a time while the other modem could only be receiving data. This one direction at a time transmission is known as half-duplex.

Modems that interfaced to a dial-up circuit had to support this half-duplex transmission method. What this meant was that once the two modems completed initial

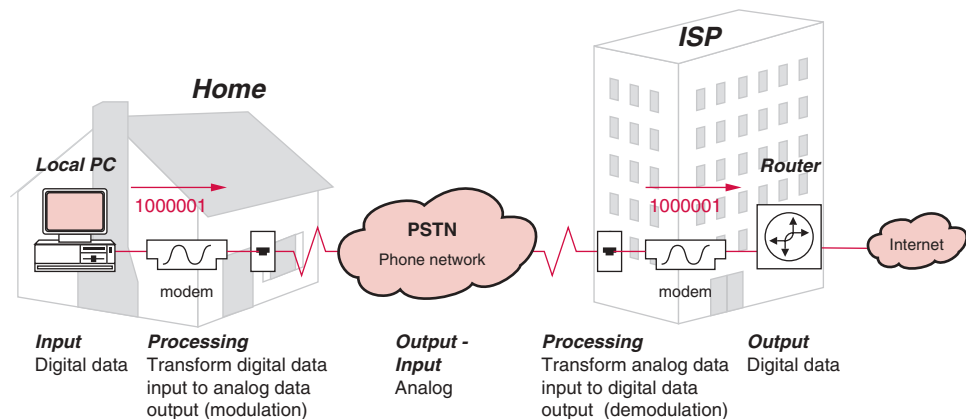


Figure 3-16 I-P-O Analysis: Modems and the PSTN

**handshaking**, one modem would agree to transmit while the other received. In order for the modems to reverse roles, the initially transmitting DTE (terminal or computer) drops its RTS (request to send) RS-232 Pin # 4 and the transmitting DCE (modem) drops its CTS (clear to send) RS-232 Pin # 5, and perhaps its carrier wave. Next, the initially receiving DTE must raise RTS, the initially receiving DCE (modem) must generate a carrier wave and raise CTS, and the role reversal is complete.

This role reversal is known as **turnaround time** and can take two-tenths of a second or longer. This might not seem like a very long time, but if this role-reversal needed to be done several thousand times over a long-distance circuit, charged by usage time, it might have a large dollar impact.

Full-duplex transmission supports simultaneous data signaling in both directions. Full-duplex transmission might seem to be impossible on two-wire circuits. Until the advent of the V.32 9,600 bps full-duplex modem, the only way to get full-duplex transmission was to lease a four-wire circuit. Two wires (signal and ground) were for transmitting data and two wires (signal and ground) were for receiving data. There was no “role reversal” necessary and therefore, no modem turnaround time delays. Modems manufactured to the CCITT’s V.32 standard (and the later V.34 standard) can transmit in full-duplex mode, thereby receiving and transmitting simultaneously over dial-up two-wire circuits using a sophisticated **echo cancellation** technique.

Echo cancellation takes advantage of sophisticated technology known as **digital signal processors (DSP)** that are included in modems that offer echo cancellation. By first testing the echo characteristics of a given phone line at modem initialization time, these DSPs are able to actually distinguish the echoed transmission of the local modem from the intended transmission of the remote modem. By subtracting or canceling the echoed local transmission from the total data signal received, only the intended transmission from the remote modem remains to be processed by the modem and passed on to the local PC.

**Standards** In order for modems manufactured by different vendors to interoperate successfully, they must adhere to common operational standards. These standards must define methods of modulation, data compression, error correction, and auto-dialing, and must provide backward compatibility with older standards. Figure 3-17 summarizes significant dial-up modem standards of the last 20 years.

The V series standards featured in Figure 3-17 are officially sanctioned by ITU-T (International Telecommunications Union—Telephony Sector). The Bell standards listed in Figure 3-17 are pre-divestiture standards from the time when AT&T dictated modem specifications in the United States and compliance with international standards was not an option. The suffix “bis” refers to the second standard issued by a given standard committee, while the suffix “ter” refers to the third standard issued by that same committee.



Practical Advice  
and Information

### NON-STANDARD STANDARDS

In an effort to gain market share during the time when standards-making organizations are deliberating new standards, vendors often introduce proprietary versions of pending standards. Before the standardization of V.90 there were two proprietary 56 Kbps modem technologies: X2 from 3COM/US Robotics and K56flex from Lucent Technologies.

One very important point to keep in mind when purchasing pre-standard data communications equipment is the ability of the vendor to upgrade that equipment to

Modem Standard	Transmission Rate	Baud Rate	Data Compression	Error Correction	Modulation Method
<b>V.90</b>	56 Kbps down, 28.8 Kbps up	3,200, 3,000, 2,400, 2,743, 2,800, 3,429, baud	V.42bis/MNP5	V.42/MNP4	Digital downlink & 9QAM & TCM uplink
<b>V.34</b>	28.8 Kbps 33.6 Kbps (optional)	3,200, 3,000, 2,400, 2,743, 2,800, 3,429, baud	V.42bis/MNP5	V.42/MNP4	9QAM & TCM
<b>V.32 ter</b>	19.2 Kbps	2,400 baud	V.42bis/MNP5	V.42/MNP4	8QAM & TCM
<b>V.32 bis</b>	14.4 Kbps	2,400 baud	V.42bis/MNP5	V.42/MNP4	6QAM & TCM
<b>V.32</b>	9.6 Kbps	2,400 baud	V.42bis/MNP5	V.42/MNP4	4QAM & TCM
<b>V.22 bis</b>	2,400 bps	600 baud	V.42bis/MNP5	V.42/MNP4	4QAM & TCM
<b>Bell 212A</b>	1,200 bps	600 baud			4PSK
<b>Bell 103</b>	300 bps	300 baud			FSK

**Figure 3-17** Modem Standards

meet the specifications of the official standard once it is issued. In some cases, software upgrades are possible, while in other cases, hardware upgrades or chip replacement is required. In some cases, these upgrades may be free and easily accomplished via the Internet, while in other cases, the upgrade may involve returning the equipment to the factory, involving upgrade fees of several hundreds of dollars. Be sure to understand all of the details regarding standards compliance upgrades before ever purchasing pre-standards data communications equipment.

**V.34** V.34 offers a transmission rate of up to 33.6 Kbps (33,600 bps) over the standard analog local loop. The highest required speed for a V.34 compliant modem is 28.8 Kbps. The 33.6 Kbps speed is available for modems that make use of an optional baud rate. As shown in Figure 3-17, the higher speed is achieved by using a lower baud rate with more bits per baud than the required 28.8 Kbps speed.

It is important to note that although modulation standards have changed in order to produce higher transmission rates, the associated data compression and error correction standards have remained constant. The V.34 modem standard instituted a variety of technical innovations in order to achieve this transmission rate over dial-up lines of variable quality. The overall effect of these technical innovations is that the V.34 modem is better able than any previous modem standard to easily and dynamically adjust to variable line conditions in order to optimize transmission rate.



**V.34 TECHNICAL INNOVATIONS**

Figure 3-18 summarizes the technical innovations introduced with the V.34 modem standard and their associated importance or implication.

Although all of the technical innovations listed in Figure 3-18 are considered part of the V.34 standard, it is not safe to assume that they are all included in any V.34 modem. In addition, several other optional features may or may not be supported on any given V.34 modem:

- Support of leased lines as well as dial-up lines
- Inclusion of four-wire as well as two-wire physical interfaces
- Password protection and callback security

V.34 Technical Innovation	Importance/Implication
<b>Multiple baud rates/ Carrier frequencies</b>	The V.34 standard specifies three required baud rates (3,200, 3,000, 2,400) and three optional baud rates (3,429, 2,800, 2,743). Multiple potential baud rates increase the V.34 modem’s ability to adapt to variable line conditions. Each baud rate supports two different carrier frequencies in order to optimize transmission speed on dial-up lines of variable quality.
<b>Baud rates greater than 2,400</b>	The V.34 standard is the first to attempt baud rates of greater than 2,400. The 28.8Kbps transmission rate is achieved by interpreting 9 data bits per baud at a baud rate of 3,200. The 33.6 Kbps transmission rate is achieved by interpreting 12 bits per baud at a baud rate of 2,800.
<b>Auxiliary management channel</b>	An auxiliary or side channel, separate from the data channel, is available for transmission of management or configuration data. This channel would be particularly important if the V.34 modem were attached to a router or similar internetworking device that might require monitoring or management without disrupting the main data traffic.
<b>Asymmetric transmit/ receive speeds</b>	Some applications such as database queries/responses, or Web requests/downloads, may require wide bandwidth in one direction only. V.34 specifies a method for allocating the data with a larger bandwidth in one direction than the other.
<b>Adaptive line probing</b>	Adaptive line probing tests the characteristics of the transmission line not just at call initiation time, but throughout the transmission. Changes in baud rate, carrier frequency, constellation size and shape and other parameters can be changed in order to optimize transmission rate.
<b>Precoding and nonlinear encoding</b>	Reduces high-frequency line noise and increases immunity to interference on analog to digital conversion by plotting constellation points in areas with less interference.
<b>Fallback/Fallforward</b>	Although many modem standards support fallback, V.34 supports fall-forward features that allow increases in transmission rates as line conditions improve.
<b>Trellis coded modulation</b>	A forward error correction methodology that helps support higher baud rates on dirty phone lines by predicting the location of a given constellation point. Can add significant processing overhead.
<b>V.8 Training specification</b>	Also known as fast-training, this specification allows two V.34 modems that support V.8 training to set-up and initialize a call faster than modems that do not support V.8.

**Figure 3-18** V.34 Technical Innovations

- Ability to connect to fax machines via the V.17 FAX standard
- Ability to auto-dial via the V.25bis autodial standard
- Auto-dial backup for failed leased lines or lost carrier
- Auto restoral to repaired leased lines

This lack of assurance as to the exact features supported on any given V.34 can lead to interoperability problems among V.34 modems. The best solution to this dilemma is to purchase identical modems from a single manufacturer. If this is not practical, then the time invested to carefully investigate which features of the V.34 standard are implemented in a given modem would be a wise investment indeed.

**V.90** According to Shannon's Law the highest V.34 transmission rate of 33.6 Kbps should be the maximum transmission rate that a voice-grade telephone line can support. However, Figure 3-17 claims that modems that adhere to the V.90 standard are capable of transferring data in at least one direction at speeds up to 56 Kbps per second. How can this be? Were telecommunications engineers able to change the laws of physics?

The answer is obviously no. Shannon's law is still intact for data transmission across the PSTN. The telecommunications engineers instead changed the paradigm in order to alleviate one of the largest components of noise in a traditional modem implementation. The resulting standard, known as **V.90**, is a hybrid analog/digital standard that offers transmission rates of almost double V.34 levels.

A preview of chapter 5 shows that the majority of the telephone system is currently digital in nature with the local loops from the central offices to the end users being the only remaining analog connections. An analog telephone signal is converted into a digital signal at the Central Office (CO) for transmission across this digital telephone system then converted back into an analog signal at the destination CO for transmission to the destination telephone across the destination local loop.

The limiting factor in exceeding V.34 speeds is the quantization noise associated with the conversion of the analog signal to a digital signal for transmission across the digital telephone system. In order to exceed V.34 speeds this analog to digital conversion and its associated quantization noise must be eliminated. Fortunately the digital nature of the modern PSTN makes this possible.

### QUANTIZATION NOISE

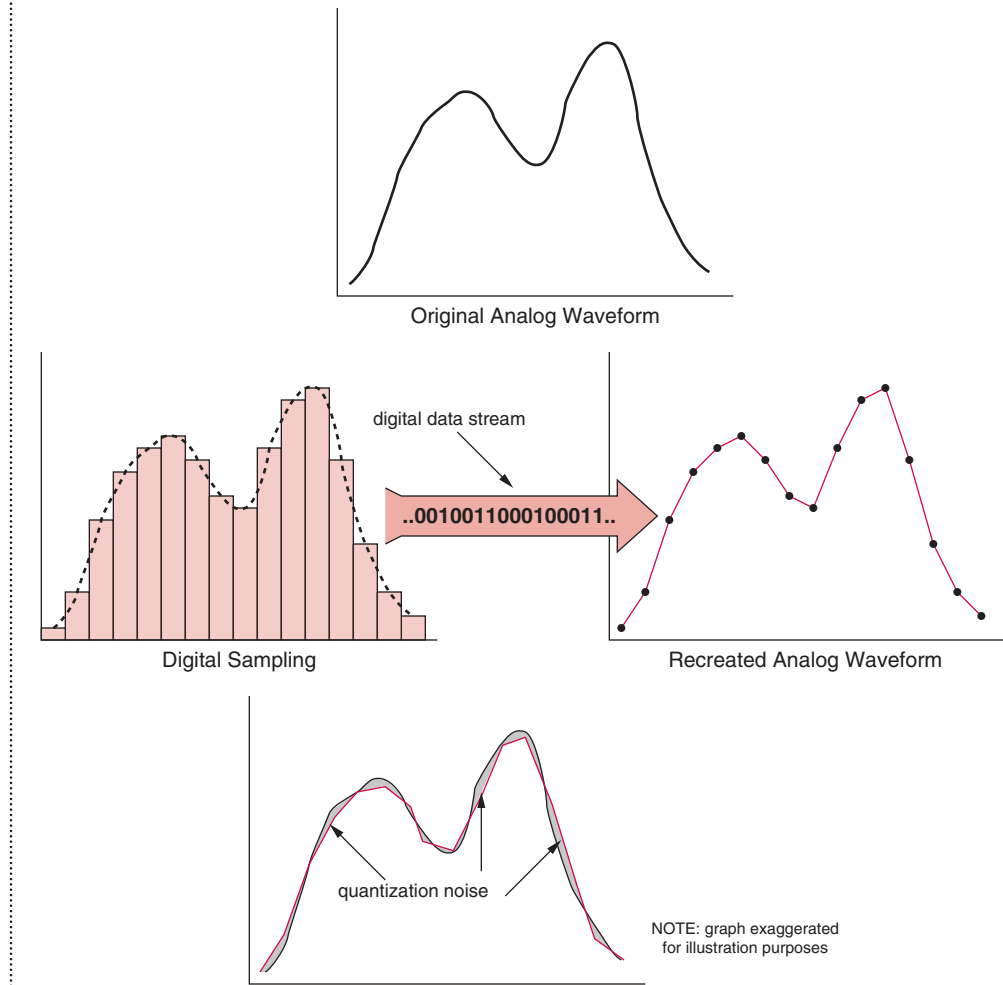
Conversion of a signal from an analog format to a digital format imparts "noise" into the signal. This can be readily explained by considering the nature of both analog and digital signals. Analog signals can consist of any possible level. Digital signals can consist only of fixed levels.

As shown in Figure 3-19, when an analog signal is sampled and converted into a digital signal, a certain level of detail is lost. When the digital signal is converted back into an analog signal at the destination end of the call, the resulting analog waveform is not exactly equal to the source waveform. This error is known as **quantization noise** or **quantization error**.

While quantization noise is not perceivable by humans on normal telephone calls, it affects the ability of modems to use the entire bandwidth of the call, thus limiting the potential transmission rate. It is important to note that quantization noise is created by the analog to digital conversion process, although it does not manifest itself until subsequent digital to analog conversion.



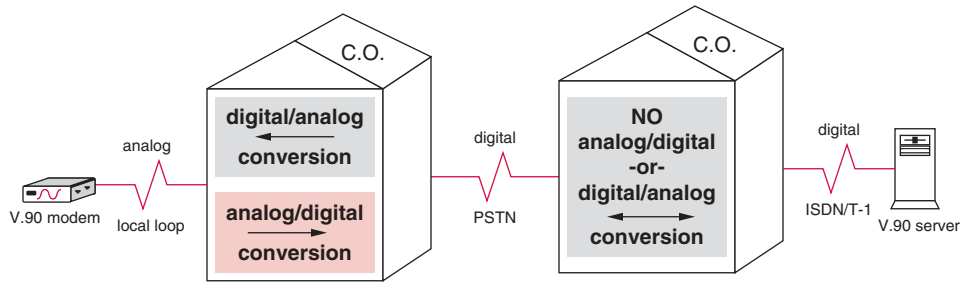
In Sharper Focus



**Figure 3-19** Quantization Noise

The V.90 modem standard makes use of the digital PSTN to overcome quantization noise by replacing the analog modem on one end of the connection with a digital server. This server connects directly to its Central Office (CO) via a digital connection such as an ISDN PRI or T-1 line. By using a direct digital connection, the server avoids any analog to digital conversions for outgoing transmission, thereby eliminating quantization noise. At the other end of the connection the CO converts the digital signal into a clean analog signal and transmits it to the destination modem. This process is illustrated in Figure 3-20.

By using this technique, a theoretical transmission rate of 56 Kbps can be achieved from the server to the modem. Note that this is a theoretical rate. An FCC limit on the amount of power allowed on the local loop reduces this theoretical limit to around 53 Kbps. Physical limitations in the local loop—including the distance from the modem to the CO, the number of connections or splices in the local loop, and the overall quality of the local loop—can limit the actual transmission rates further. In the authors' experience it is far more common to achieve transmission rates of around 44 Kbps, although connections at rates in excess of 50 Kbps have been noted.



**Figure 3-20** V.90 Implementation

A close examination of Figure 3-20 shows that the increased speed offered by V.90 is limited to the half of the connection originating at the server and terminating at the modem. The other half of the connection, originating at the modem and terminating at the server, must undergo an analog to digital conversion and therefore incurs quantization error, limiting speeds to V.34 levels. Because the speeds are different in each direction, V.90 is said to be an **asymmetrical transmission** technology.

Fortunately, the asymmetrical characteristic of V.90 matches the asymmetrical nature of the most common modem application: accessing the Internet. In a normal Internet session, a user sends a fairly short request (such as the address of a Web page) to a server. The server responds with a much larger collection of data (such the text and graphics that make up the Web page) to the user; making V.90 a natural fit for Internet access.

As with all modern modem standards, V.90 compliant modems are backward compatible with earlier standards. When a connection is initially made, the modem will attempt to connect at the highest possible V.90 speed. It will then drop back to slower V.90 levels, then resort to V.34 levels, V.32 levels, and so on, until a carrier wave can be established. Because of this automatic rate fallback strategy, it is common for first-time users to comment on the long time required for a V.90 modem to establish a carrier and begin communicating.

**Data Compression and Error Correction Standards** By operating more efficiently, modems are able to offer more transmitted data in a given amount of time. Although several factors can lead to increased modem efficiency, data compression can have the most significant impact in the amount of data actually delivered by a given modem in a given amount of time.

**Data Compression** As introduced in chapter 2, data compression replaces large strings of repeating character patterns with a special code that represents the pattern. The code is then sent to the other modem. From that point forward, the sending modem sends the code instead of the original pattern. As the code is significantly smaller than the pattern it represents, the amount of data sent between the two modems is reduced, up to 400 percent under optimal conditions. The process of data reduction is similar in concept to having more than one bit per baud, as covered in the previous chapter.

By using data compression, a 28.8Kbps (V.34) modem could optimally transfer 115.2Kbps ( $28.8 \text{ Kbps} \times \text{compression factor of } 4:1$ ) of data across a dial-up phone line. In this scenario, the 115,200 bps is known as *throughput*, while the transmission rate remains at or below the V.34 maximum of 28.8Kbps.

**V.42bis and MNP 5** The two predominant data compression standards are V.42 bis and MNP5. Most modems try to negotiate with each other to implement V.42bis data compression at initialization. The less-efficient MNP5 protocol is commonly used as a second option.

**V.42bis** uses a data compression algorithm known as the Lempel Ziv algorithm. Ideally, it can compress files, and thereby increase throughput by a 4:1 ratio. Proprietary improvements to this algorithm by modem manufacturers can be achieved in two ways:

- Increase the amount of memory dedicated to the library, also known as the dictionary (1.5KB standard, some modems use up to 6KB).
- Increase the size of the pattern of characters, also known as string size, which can be stored in the dictionary (32 bytes standard, some modems support strings up to 256 bytes).

Proprietary improvements to standards such as V.42bis are only effective when both modems involved in a transmission are identical. It should also be noted that most independent modem testing suggests that compression ratios in the range of 2.5:1 are most likely, despite higher optimal claims.

**MNP Class 5** yields data compression ratios in the range of between 1.3:1 and 2:1. MNP5 uses two data compression algorithms:

- *Huffman encoding* is a special character encoding scheme that re-encodes ASCII characters. Frequently used characters such as “a”, “e” and “s”, are encoded with only 4 bits, while rarely occurring characters such as “x” or “z” are encoded using as many as 11 bits. Overall, the effect of Huffman encoding is that more characters are transmitted using fewer bits.
- *Run-length encoding* exams a datastream in search of repeating characters. When any character repeats more than three times, the run-length encoding algorithm replaces the entire string of repeated characters with only three repetitions of the character followed by a count field indicating how many times the character is actually repeated. For example, a data string containing 10 consecutive repetitions of the same character would be replaced by 3 repetitions of that character followed by a 1-byte count character. This would reduce the string in question from 10 bytes to 4 bytes, for a savings of 60 percent. Repeated characters can include nonprinting characters such as spaces, carriage returns, and line feeds.

Improving the reliability of the data transmission link between two modems will ultimately make that data transmission faster and more efficient. Fewer retransmissions due to data errors will reduce the overhead associated with correcting errors, thus reducing the time necessary to transmit a given message. This will minimize the cost of the data transmission.

**Error Prevention** Data transmission errors occur when received data is misinterpreted due to noise or interference on the phone lines over which the data message traveled. Errors can be prevented by

- Reducing the amount of noise or interference on a given transmission line
- Employing modulation techniques that are able to adapt to and overcome noisy lines

**Line Conditioning, Repeaters, and Amplifiers** **Line conditioning** is a value-added service available for analog leased lines from the phone company. Various levels of conditioning are available at prices that increase proportionally to the level of conditioning, or noise reduction, requested. Conditioning represents a promise from the phone company in terms of the noise levels or interference present on a given analog leased line. In order to deliver on this promise, the phone company might have to install additional equipment.

A **repeater** is often used by a phone company to assure signal quality over the entire length of a circuit. As a signal travels through a medium such as copper wire, it loses some of its strength due to the resistance of the wire. This loss of signal strength or volume is known as attenuation.

A repeater on an analog circuit, sometimes called an **amplifier**, strengthens and repeats the signal. Unfortunately, on an analog circuit the amplifier cannot distinguish between the voice or data signal and the background noise. As a result, the amplifier strengthens and repeats both signal and the background noise.

Repeaters on digital circuits are able to distinguish the digital signals from the background noise. Therefore, digital repeaters can retransmit a digital signal free of noise, ensuring that the signal will reliably arrive at its destination without the need for specialized line conditioning.

**Adaptive Protocols** Another way in which errors can be prevented during data transmission is through the use of **adaptive protocols**. Adaptive protocols adjust transmission session parameters in response to varying line conditions. The MNP Classes of networking protocols offer several examples of such adaptive protocols.

**Adaptive Size Packet Assembly** is an **MNP Class 4** protocol that can increase or decrease the amount of data sent in each packet according to the current condition of the transmission circuit. A packet that includes data and overhead information is analogous to a handwritten message (the data) plus a sealed, addressed envelope (the overhead). This protocol tries to optimize the amount of data per packet by building packets containing the greatest amount of data that can be transmitted reliably and therefore, not require retransmission.

Optimal packet size is a moving target, changing with line conditions. Each packet of data contains overhead. Therefore, if line conditions are good, it makes sense to use large packets to maximize the data to overhead ration. Returning to the previous analogy, it would be advantageous to write as long a letter as possible for each envelope. Too little data per packet and time is wasted processing overhead (opening envelopes in the analogy).

However, if line conditions are poor, errors will occur. Because the error detection process can only determine that an error occurred in the packet rather than the exact bit in error, the entire packet containing the error must be retransmitted. The larger the packets are, the more data that must be retransmitted for each error. In our analogy this correlates to receiving, rewriting and remailing letters for insufficient postage. Adaptive Size Packet Assembly solves the data per packet dilemma by adapting the amount of data included in each packet according to varying line conditions. When errors are detected, packet size is reduced. When no errors are detected over a period of time, packet sizes are increased.

**Dynamic Speed Shifts** is an **MNP Class 10** adaptive protocol that allows two modems to change speeds up or down (faster or slower) in the midst of their data transmission in response to varying line conditions. The adaptive nature of this protocol assures that the highest practical transmission speed will be used at all times, dependent upon current line conditions. This adaptive protocol is especially useful

in cellular phone environments in which line quality can vary significantly over short periods of time.



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### ADAPTIVE PROTOCOLS CAN MASK PROBLEMS

Dynamic Speed Shifts or any adaptive protocol can be a double-edged sword, however. In the event of degraded line quality, MNP 10 modems may automatically downgrade their transmission speeds. Unless a personnel procedure is in place to take note of the lower transmission speed, the problem might go undetected and unreported to the carrier for an extended period of time.

**Forward Error Correction** Sophisticated error correction techniques exist that send sufficient redundant data to the receiving modem to enable it to not only detect, but also to correct data transmission errors without the need for retransmission. Forward error correction works in a similar manner to the data correction techniques previously explained. On the transmitting side, the incoming data signal is processed and redundant code bits are generated based on that incoming signal. These additional redundant bits are added to the original signal and transmitted to the receiving device. The receiving device processes the incoming data signal in the same manner as the transmitting device and regenerates the redundant code bits. The transmitted redundant code bits are compared with the redundant code bits regenerated by the receiving modem. If they match, then no errors have occurred on the incoming signal. If they don't match, the forward error correction circuitry at the receiving device uses the transmitted redundant bits to correct the incoming data signal, thereby correcting transmission errors without the need for retransmission.

However, there is a downside to forward error correction. In data communications, just as in life, you can't get something for nothing. In order to give the receiving modem sufficient redundant data to be able to correct its own detected errors, the overall throughput of informational data on the circuit is reduced. This process, known as **forward error correction**, tries to favorably balance how much redundant data can be sent *up front*, thereby avoiding retransmissions, to maximize overall throughput on the circuit. It's a bit of a gamble, really:

- If not enough redundant data are sent, the overall throughput is reduced due to retransmissions.
- If too much redundant data are sent, the overall throughput is reduced because the redundant data is taking up space and processing power that could be occupied by "new" non-redundant data.

**Trellis Coded Modulation** **Trellis coded modulation (TCM)** is another way in which transmission errors can be overcome without the need for retransmission. Modems that employ TCM are able to overcome twice as much noise on a given circuit as QAM modems that don't employ TCM. Intersymbol interference can cause a modem to detect the wrong constellation point and subsequently interpret that constellation point into an incorrect sequence of bits. Using a sophisticated technique known as **convolutional encoding**, TCM adds a redundant bit that limits the possible valid constellation points for the current transmission. By limiting the number of possible constellation points that are potentially valid for any given symbol received, the modem is able to avoid misinterpreting symbols that would ordinarily lead to retransmissions in order to correct the error.

For example, if we wanted to send 6 data bits per baud, we would ordinarily require a 64-point constellation ( $2^6$ ). However, by adding a 7th TCM code bit to each 6 data bits, a 128-point constellation would be generated ( $2^7$ ). But remember, only 64 constellation points are required to transmit the original 6 data bits per baud, so only 64 of the 128 possible detectable constellation points are defined as valid. If one of the invalid constellation points is detected, the TCM circuitry selects the most likely valid constellation point and its associated pattern of bits. In this manner, TCM reduces errors and the need for retransmission due to line impairments. However, error detection and correction techniques must still be employed.

The sophistication of a given TCM scheme is measured by the number of potential trellis codes or states. The greater the number of TCM states, the higher the required processing power in the modems, and the higher immunity to inter-symbol interference due to line noise. TCM was first introduced as part of the V.32 modem standard and is supported by V.34 and V.90 modems.

**MNP4** The MNP error control standards were originally developed by Microcom, a modem manufacturer. The MNP standards include Classes 2, 3, and 4. These error control standards optimize the full-duplex transmission of data over dial-up lines through Adaptive Size Packet Assembly and the elimination of redundant or overhead information from transmissions.

**V.42** Not to be confused with the CCITT V.42bis standard for data compression, V.42 incorporates MNP Class 4 Error Control as the first of two possible error control protocols. In addition, a second error control protocol known as **Link Access Protocol for Modems**, or **LAP-M**, adds Selective ARQ to the capabilities of MNP Class 4 Error Control protocol. Selective ARQ, described earlier, only requires retransmission of specific blocks received in error rather than all blocks subsequent to the block in which the error was detected. V.42 also provides for negotiation during modem handshaking to allow two modems to decide whether they will implement MNP 4 or LAP-M as an error control protocol for their data transmission.



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### HARDWARE VS. SOFTWARE ERROR CONTROL

MNP 4 and V.42 are error control protocols implemented within modems. Using these protocols, the modems themselves assure error-free transmission. There is no need for additional error control protocols that can be supplied by communications software packages running as an application program on a PC.

**Flow Control** There are two basic approaches to implementing flow control in a modem environment: hardware and software flow control. Hardware flow control is dependent on the use of the RS-232 serial communication standard. When using hardware flow control the Request to Send (RTS) and Clear to Send (CTS) signals are used to perform the essential elements of flow control. A transmitting device will only send data into buffer memory as long as Clear to Send is “held high” (has a five volt signal). As soon as Clear to Send is “dropped” (goes to zero volts), the transmitting device immediately ceases transmitting data.

A second flow-control mechanism is to carry embed flow control flags within the datastream itself. Special data sequences, known as flags, that mean “Stop Sending Data” (XOFF) and “Resume Sending Data” (XON) are defined. When a device cannot receive data any longer, it sends an XOFF signal to the sending device. When it can resume receiving data, it sends an XON flag to the sending device.



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## SOFTWARE VS. HARDWARE FLOW CONTROL

When using RS-232 hardware flow control is usually more reliable and faster than software flow control. Software flow control is nothing more than transmitted characters susceptible to the same transmission problems as normal data. Occasionally, an XOFF might be transmitted in error and might stop a data transmission session for no apparent reason. Second, because XON and XOFF are sent in the datastream along with all the “normal” data and must be differentiated from that data. This process takes time (adds latency) and is subject to error.

**Application** While the most ubiquitous, Internet Access Technology, dial-up modems are the least attractive from a pure performance perspective. With best case, real-world data speeds limited to around 45 Kbps downstream and 33 Kbps upstream, dial-up modems are simply too slow to truly provide adequate service for an increasingly multimedia Internet.

At this point dial-up modems have three applications in the Internet access paradigm:

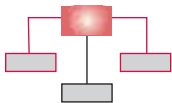
- *Travel*—PSTN lines are available at residences, hotels, and even modern pay phones. When combined with a national ISP, a dial-up modem can provide Internet access just about anywhere.
- *Cost*—Dial-up modems continue to be the least expensive Internet access technology in terms of base monthly fee. However, when looking at the cost/MB of data downloaded, dial-up trails faster technologies by a significant margin. If a full-time connection is required, the cost of a second phone line can quickly drive the cost of dial-up higher than faster alternatives.
- *Last resort*—Dial-up Internet access is available virtually everywhere, even those places where other, faster alternatives are not yet available. In some cases, it is simply dial-up or nothing.

Beyond the Internet access paradigm, dial-up modems have other applications, including serving as a backup connection for other technologies such as the wide area networking connections detailed in chapter 6. If the primary connection fails, a dial-up connection is established to the destination to enable business to continue. However, due to the reduced speed of a dial-up connection, care must be taken to ensure that the limited bandwidth is used for the mission-critical applications by preventing other, less critical applications from using the connection.

## LEASED LINE BACKUP

Coping with leased-line failure requires a business decision. The technology is available to backup failed leased lines by automatically establishing connections via dial-up lines between points on the failed circuit. However, there are at least two incremental costs involved in this automatic backup. First, there is the cost of the additional technology necessary to detect the leased-line failure and establish the dial-up connection. Second, dial-up circuits must be available for the auto dial backup unit to utilize in the event of a leased line failure. These dial-up circuits would incur both installation and monthly charges, whether they are used or not.

In addition, if the established dial backup connection is long distance, then per-minute usage charges for the dial-up lines could amount to a significant incremental



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cost. The other side of the cost/benefit equation would require the following question to be asked, “What is the cost of the business lost during the time that the leased line is down?” If that lost business can be translated into lost sales dollars in excess of the incremental cost of establishing and maintaining the dial-up backup for the failed leased line, then the acquisition of the equipment and phone lines to enable automatic backup would constitute a prudent business decision.

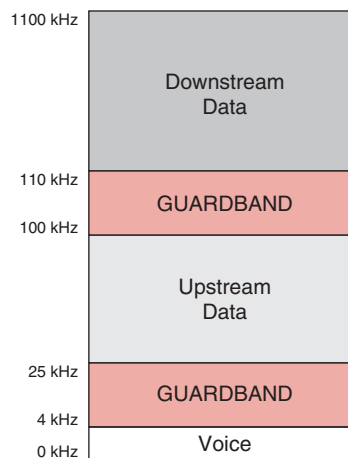
### Digital Subscriber Line (DSL)

As the Internet has matured, so has the sophistication of the content it carries. With Web pages growing in size due to the addition of animation and graphics, the explosion of file sharing using networks such as Kazaa, and the promise of real-time voice and video communication, dial-up modems have become too slow to meet the needs of the Internet consumer and are being phased out in favor of “broadband” access technologies. Broadband has many definitions, but the simplest is to consider any access technology that provides access to the Internet at greater than 56 Kbps to be a **broadband** technology.

One of the faster broadband technologies currently available is **Digital Subscriber Line (DSL)**. DSL provides an “always on” connection to the Internet over the same copper wires that provide dial-up telephone service.

**Architecture** DSL uses the same physical local loop connection as the local phone service used in POTS, as illustrated in Figure 3-15. When a local loop is used for DSL frequency division multiplexing is used to separate the existing voice service from the DSL service. As detailed earlier in this chapter, a POTS line uses only the bottom 4 KHz of bandwidth on the copper loop. All of the bandwidth above is available for an alternate service, such as DSL.

As illustrated in Figure 3-21, DSL operates above the POTS frequency range. In the figure the DSL service operates between 25 KHz and 1,100 KHz. This frequency range is further broken into two parts for upstream and downstream data. Upstream uses between 25 KHz and 100 KHz. Downstream data uses 110 KHz to 1100 KHz. This is



**Figure 3-21** Frequency Division Multiplexing in DSL

an example of an asynchronous link. Because the amount of bandwidth given to the downstream link is larger than that given to the upstream link, the connection supports a proportionally higher downstream data transfer speed. This type of DSL service is commonly referred to as an **Asymmetrical Digital Subscriber Line (ADSL)**.

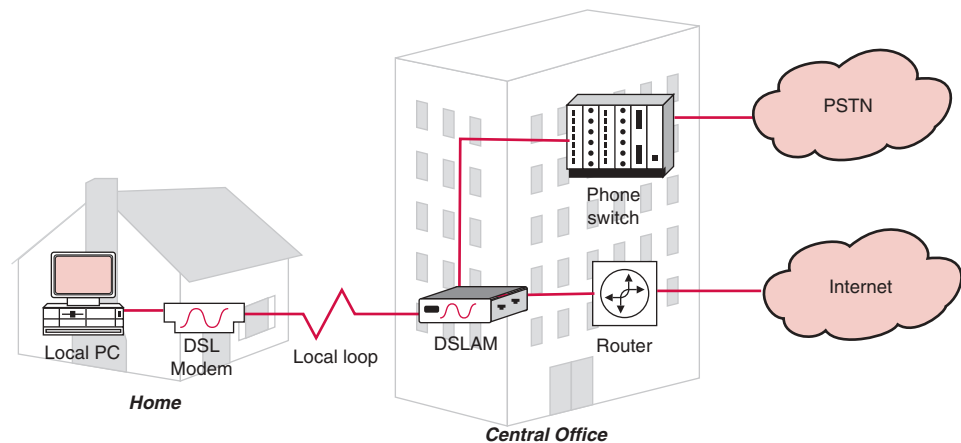
Because DSL uses the same copper loop as a POTS line, it reduces the cost to the DSL provider. If additional copper wires are needed to deliver service, the DSL provider would have to send out a technician to install the additional wire, increasing the cost of installation with a corresponding increase in DSL service cost.

In order to support DSL service, additional equipment must be installed in the central office (CO) and the customer home (also known as the customer premises). As illustrated in Figure 3-22, this equipment includes a DSL modem at the customer premises and a **Digital Subscriber Line Access Multiplexer (DSLAM)** at the central office.

A DSL modem is installed at the customer's premises. This modem works like the dial-up modems discussed earlier in the chapter in that it takes digital signals from your computer and converts it to analog signals for transmission over the local loop to the central office using the same digital to analog modulation technologies as a dial-up modem. The key differences are that the DSL modem doesn't need to "dial up" the central office equipment every time you want to connect to the Internet: the central office is always at the other end of the local loop connection.

When the modem is initially powered on, it communicates with the DSLAM at the central office. The two devices then determine the optimal speed based on the quality of the connection over the copper pair and establish a connection. This connection is a point-to-point connection between the modem and the central office. The customer is the only person using the local loop between the central office and the customer premise. The connection remains live until the modem is powered down.

A DSL modem connects to any phone jack at the customer premise using a standard RJ-11 phone connection to receive the analog data signal from the DSLAM. The DSL modem then un-modulates the signal and provides it to your computer (or other network device) via a second port. The majority of the DSL modems in use today use a standard Ethernet for this connection. The Ethernet port would be connected to an Ethernet network interface card (NIC) in your PC or other network device use as a firewall/router. Some DSL modems may use a USB connection to



**Figure 3-22** DSL Architecture

connect to the computer in place of the Ethernet connection. If the modem only supplies a USB connection it must be connected to a computer rather than another network device.

A DSLAM is installed on the central office. This device is analogous to a modem bank in a dial-up environment. It takes multiple incoming DSL local loops, demodulates their datastreams, and multiplexes them onto a high-speed connection for transmission to the ISP. These high-speed connections can vary from a T1 to frame relay, to an OC-3 SONET connection. For more information about these technologies, please refer to chapter 6. After stripping the data signal from the local loop the DSLAM sends the underlying POTS signal to the dial-up telephone switch.

DSL modems and DSLAMs are layer two devices: they simply pass the data between them without interpreting it. From the perspective of the user at the customer premises the DSL modem and DSLAM are invisible.

**Standards and Technology** Unlike dial-up modems, there is little standardization in the DSL world. Different vendors have developed different solutions that use different frequencies and modulation schemes. Fortunately, the only two devices that have to agree on the DSL technology used are the DSL modem and the DSLAM. For this reason, most DSL service providers require customers to rent or purchase DSL modems directly from them. This is diametrically opposite the approach taken in cable modem environments.

There are several different DSL standards deployed. The key differences between these technologies are the data transmission speeds they provide, the distance over which they travel, and their reliability and resistance to noise. A matrix of commonly available DSL services is provided in Figure 3-23.

DSL Technology	Maximum Speed	Pairs of copper needed	Distance Limitation	Application
ADSL (Asymmetrical DSL)	Up to 8 Mbps downstream 640Kbps upstream	1	Up to 18,000 ft.	Consumer Internet access
IDSL (ISDN DSL)	144 Kbps downstream 144 Kbps upstream	2	Up to 18,000 ft. (additional equipment can extend distance)	ISDN replacement and business Internet access
SDSL (Symmetrical DSL)	1.544 Mbps downstream 1.544 Mbps upstream	1	Up to 10,000 ft.	Business Internet access
HDSL (High bit rate DSL)	1.544 Mbps downstream 1.544Mbps upstream	2	12,000 to 15,000 ft.	T-1 replacement and business Internet access
VDSL (Very high bit rate DSL)	up to 34 Mbps upstream and downstream, if symmetric	1	Max. of 4,000 ft.	Business Internet access

**Figure 3-23** DSL Comparison Matrix

**Implementation and Performance** A few items affect the speed of DSL services. The first item is the copper local loop. The quality of the copper in the ground is a major factor. If you live in an area built in the early 1950s, the copper installed in the ground is older and might have degraded over time. If you live in a newly constructed area, the copper could be newer and made with more modern manufacturing techniques. The quality of the copper is something you may not be able to fix, but it is something you need to be aware of when dealing with DSL.

Another item that affects the speed of DSL is the distance you are from the central office. The farther you are from the central office, the longer the analog signal needs to travel over the copper. As analog signals travel over copper over a distance, the signal degrades in power. This signal loss affects the speed at which DSL operates. In areas where the DSL modem is close to the central office, the DSL modem may run near its theoretical speeds. In locations where you are farther away from the central office, the DSL modem will not operate at the theoretical speeds, but will generally operate at a speed faster than dial-up modems.

**Splitter and Media Filters** A **splitter** would be installed on the outside of the house by the telephone company. The goal is to separate the data service from the voice service. This was needed due to the nature of how phone service works. When a phone goes off hook, a power spike is caused by the contacts opening up on the phone switch. The power spike sends a frequency blip over the entire frequency spectrum allowed to pass over the copper pair. The frequency blip, if not stopped, would cause the DSL modem to “momentarily” drop connection with the DSLAM in the central office. This would cause data to be lost and the modem would have to reestablish their connection.

Early DSL modems required these splitters to be installed to eliminate the possibility of phone calls affecting the data service. The splitter separated the wiring inside the house to a phone set of connections and a single data connection. The phone connection also had a device installed to eliminate the power spike. The installation of the splitter increased the cost of the service due to the labor of the person from the telephone company being required to visit each residence to install the splitter. A consumer installation method was required that would eliminate the *truck roll*, thus lowering the cost and decreasing the time it took to turn up each service. The solution was found in the use of **media filter**.

Media filters are sent with the DSL modem and installed by the consumer. Media filters are wire-wrapped magnets that are installed on each phone in the house that is connected to the phone line the DSL is on. The goal of the filter is to suppress the high-voltage spike that occurs when a traditional phone is taken “off hook.” Media filters absorb the frequency blip and allow the DSL modem to work without interruption.

**Consumer Class vs. Business Class DSL** As discussed above, DSL can be used for both business and consumer access to the Internet. As you would expect, business-class DSL cost more than consumer-class service. Consumer-class DSL usually uses DHCP for IP addressing and usually allocates 1 IP address per DSL modem. The bandwidth allocation is generally more in the downstream direction and the upstream direction. This matches the wants of most consumers: they need to get more information from the Internet than they send.

Business-class DSL generally allocates a static IP address to the business. Additional IP addresses can be purchased, for a cost. Businesses generally want to run a Web site from their location, so the data requirements are different than the

“standard” consumer. Bandwidth allocation is generally more symmetrically with speed moving toward T1 speeds (1.544Mbps upstream and downstream). The business might also want the ISP to supply e-mail services for all their employees. This will also increase the cost.

If a consumer needs some of the features that a business would need, the providers are more than happy to sell them a business class DSL connection. The only catch is that they will pay the same cost as the business would. Some providers do offer a more cost-effective consumer solution that deletes some of the other key features that a business user would need.

**Future of DSL** The future of DSL is focused on providing new services over the DSL modem. DSL providers would like to provide audio and video-on-demand services over the DSL modem. Both of these services will require the need for quality of service (QoS) to allow them to work effectively. QoS will allow the user to make voice calls over the Internet, stream video to PC, and download files at the same time without the voice or video quality suffering from the file download.

### **Cable Modems**

A second provider of high bandwidth connectivity to customer premises is the television cable company. In fact, the cable provider’s infrastructure offers a significantly higher bandwidth to the consumer than the local loop provided by the telephone company due to the coaxial cable media used for cable television transmission.

**Architecture** Cable systems were originally designed to provide one-way communication between the programming source, known as the head end, to the consumer’s television set. Analog television programming was broadcast across the network to any and all television receivers connected to the system via coaxial cable. Splitters and amplifiers were placed in the system where needed to allow the system to grow to meet the needs of the community served. This type of cable television network looks like a tree: the head end is the root and the branches continually are split off and fed into neighborhoods.

Modern cable networks have evolved to support two-way communication in addition to one-way, broadcast communication with increased bandwidth available. The increased bandwidth can be used by the cable company to offer a larger number of television channels in either analog or digital form, offer on-demand television where a customer can request movies to be sent directly to their home, and offer interactive Internet access.

To offer bi-directional Internet access, frequency division multiplexing is used to reallocate the bandwidth for one television channel (in the 50 to 750 MHz range) for downstream traffic and another channel (in the 5 to 42 MHz band) is reallocated to carry upstream signals. A single downstream 6-MHz television channel can support up to 27 Mbps of downstream data throughput using 64 QAM (quadrature amplitude modulation) transmission technology. Speeds can be boosted to 36 Mbps using 256 QAM. Upstream channels may deliver 500 Kbps to 10 Mbps from homes using 16QAM or QPSK (quadrature phase shift key) modulation techniques, depending on the amount of spectrum (number of channels) allocated for service and the relative noise on the line.

Once the bandwidth to be used for Internet access has been allocated, equipment must be installed at the head end and at the customer premises. Cable modem

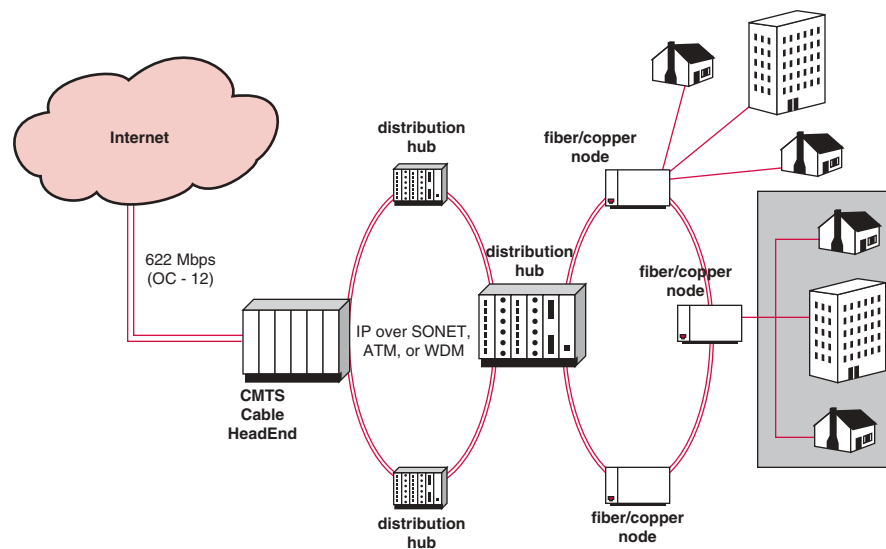
service providers use a **Cable Modem Termination System (CMTS)** to add data transmission capabilities to the existing CTV infrastructure. The CMTS is capable of providing throughput to multiple homes at rates of up to 50 Mbps. However, throughput is usually less than 27 Mbps due to the way data are transmitted to homes from the cable modem service provider.

As can be seen in Figure 3-24 the CMTS is capable of serving multiple distribution hubs, which, in turn, serve multiple fiber nodes. Each fiber node serves a *neighborhood*, or physical grouping of homes. Most groupings range from 500 to 2,000 homes on a modern, HFC network. This architecture typically results in speeds to the home of between 500 Kbps and 1.5 Mbps, depending on network congestion. Between the fiber nodes and the homes in the neighborhood, the upstream and downstream bandwidth is shared by the active data subscribers connected to a given cable network segment. A device known as a **diplexer** is used to both separate and combine the upstream and downstream signals and is located at the fiber node.

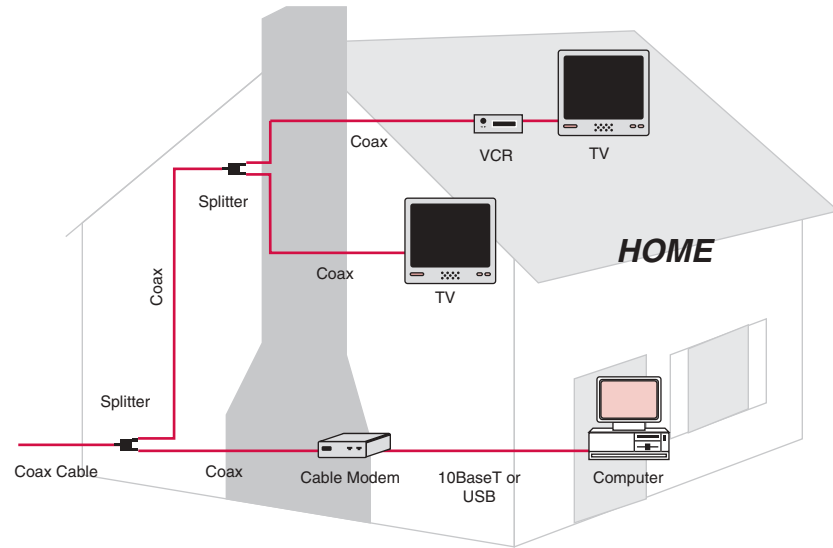
Once the coaxial cable reaches the subscriber's home, a frequency splitter is used to separate the TV signals from the data signals. Assuming the home is pre-wired for CTV, the existing wiring is used for the CTV signals. The "new" wire is connected to a cable modem, which, in turn, connects to the subscriber's PC via 10 Mbps Ethernet or, optional in newer cable modems, a USB connection. Figure 3-25 illustrates this configuration.

The function of a cable modem is essentially the reverse of the CMTS: to modulate and demodulate upstream and downstream signals, respectively. As mentioned, the CMTS uses the same techniques on the upstream and downstream signals at the head end. Downstream data is modulated at the headend using the 64-QAM modulation technique. The data occupies a 6-MHz channel somewhere in the 50 to 750 MHz range. The signal is demodulated at the cable modem side.

Upstream signals are handled differently. Like their downstream counterparts, they are modulated at the cable modem side and transmitted back to the CMTS. Because multiple cable modems must share the upstream bandwidth to the CMTS, a



**Figure 3-24** Cable Data Network Architecture



**Figure 3-25** Typical Cable Modem Installation

multiple access multiplexing scheme must be used. Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA) are commonly used to allow multiple cable modems to communicate to the CMTS concurrently. Before a cable modem can transmit to the CMTS, it must request and receive a bandwidth allocation. This is usually handled as part of the initial power-on handshaking between the cable modem and the CMTS.

**Standards and Technology** Initially, there were no standards that defined the modulation schemes used between cable modems and the CMTS. As a result, cable modem customers were locked into the cable modems offered by their cable company. In 1996, several cable operators commissioned the development of a standard, which would control compatibility of cable modem equipment, both on the user side, the cable company side, and the wiring in between. The resulting **Data Over Cable Service Interface Specification (DOCSIS)** standard defines the protocol stack used in transmissions, modulation techniques for the CMTS, and cable modem and line speeds. Both cable modems and CMTS systems can be certified as DOCSIS-compliant, which indicates all aspects of the specification are adhered to and ensures interoperability between vendors. As long as the CMTS is DOCSIS compliant, the consumer can purchase any DOCSIS-compliant cable modem with certainty that it will work with their cable system.

The DOCSIS standard also includes some security enhancements for the privacy of data. This basic privacy specification is called the BPI, or Baseline Privacy Interface. BPI allows for the use of encryption algorithms to assure the privacy of data when traveling between the user's cable modem and the cable company. It should be noted, however, that the BPI was developed to benefit the provider, not the user. The implementation of the encryption is done at the cable company, meaning subscribers have no control over whether encryption is activated or not for their shared "ring."

When activated, encryption provides several benefits, including authentication of users' modems (preventing theft of service), and virtually eliminates the sniffing threat between the cable modem and the CMTS at the cable company.

An extension to the BPI, BPI+, extends the capabilities of BPI to eliminate cloning of cable modems. Prior to the implementation of BPI+ it was possible for software or hardware to clone a cable modem and have it communicate successfully to a CMTS. BPI+ allows increased authentication by incorporating the cable modem's physical address into the encryption scheme.

**Implementation and Performance** In many ways a cable modem system has more in common with an Ethernet local area network than it does with a dial-up modem or DSL system. Unlike dial-up or DSL, where the bandwidth between the customer premises and the central office is dedicated to the customer, cable modem systems require that everyone on the cable segment share a fixed amount of bandwidth. Because of this, users might find that the service that was blazingly fast when only a few people shared the segment has grown increasingly slower as more of their neighbors connect. This shared bandwidth scenario also has security ramifications: the downstream traffic destined for one cable modem is received by all cable modems on the segment. Although each cable modem normally ignores traffic not destined for it, if placed in promiscuous mode the cable modem will pass all incoming traffic to the attached computer. For more information about broadcast shared media networks, please refer to chapter 4.

Cable modems themselves come in three forms: external, internal, and set-top box. External cable modems, by far the most popular, are physically distinct. Like all cable modems, they translate the data signal between the coaxial cable that the cable company supplies and the 10Base-T Ethernet signal the user's PC expects. This flavor of modem allows for multiple PCs to share the connection but requires a separate Ethernet network card to be installed in the subscriber's PC.

Internal cable modems are packaged as a PCI card installed in the subscriber's PC. Internal cable modems are less expensive than their external counterpart, but they are not "plug" compatible with laptop computers and Macintosh machines.

The final cable modem form factor is the set-top box, which provides network access on the subscriber's television. Set-top implementations require a separate upstream method, usually a standard dial-up modem for return signals. Typically, this type of implementation was only used for older, broadcast-only cable systems rather than modern bi-directional systems.

**Future of Cable Modems** Cable modems offer the highest Internet access connection speeds currently available. Although the shared media approach used in cable modems requires the bandwidth on an individual cable segment to be shared among the users on the segment, most cable modem customers receive excellent data speeds. As cable companies gain experience in the data communications marketplace, they are in an excellent position to leverage their existing cable plans to provide additional interactive services to consumers.

## Other Internet Access Technologies

Several other Internet access technologies are under development. One of the most interesting is fixed-point wireless. In a **fixed-point wireless** environment, the service

provider places a series of transmitters on a tower. Each transmitter is directional in nature and covers a portion of the 360 degrees around the tower. Consumers place a receiver unit in their home that connects to the tower via radio waves. Depending on their distance from the tower, consumers may need a directional external antenna to establish a radio link. Once the link is established, the consumer can access the Internet.

There are several different wireless access schemes under development, ranging from variants of IEEE 802.11 wireless LANs to licensed spectrum solutions. For more information on IEEE 802.11 networks, please refer to chapter 4.

Originally thought to best fit into urban/suburban settings, wireless Internet access is instead making its initial market penetration in rural areas. Upon closer inspection, rural areas are perfect for wireless access: there are few tall buildings to create multi-path interference in the radio signal and there are typically few competing broadband access technologies because cable and DSL providers have been focusing on more densely populated areas. Some smaller rural towns have begun proactively seeking wireless access providers to remain competitive at attracting new residents to their tax base. It is becoming increasingly common to see an antenna array installed on the top of grain elevators in small towns across the country.

Cellular telephone companies are working to develop faster Internet access technologies to serve their mobile customers. Although the cost of these services is currently too high to make them a viable choice for non-mobile users, it is too soon to rule them out as potential players in the market. These technologies are discussed in detail in chapter 5.

There are many different wide area network services available that can be used to provide Internet access. While these solutions are normally considerably more expensive than the previously discussed solutions, they offer the advantage of being dedicated to your use. A complete discussion of wide area network technologies is presented in chapter 6.



Applied Problem  
Solving

### INTERNET ACCESS TECHNOLOGY SELECTION FRAMEWORK

There is no one “best” Internet access technology solution for everyone. To help decide the best solution for a given situation the following series of questions should be answered:

- What types of service are available at the location? There may be only one choice available.
- How much bandwidth is required/desired?
- Which of the available services can meet the bandwidth requirements?
- Will Internet services such as the Web and e-mail be hosted on premises?
  - If so, an “always on” broadband service such as DSL, cable, or a wide area network solution is required.
  - Be sure to check the usage rules for any service considered. Some cable companies, for instance, have chosen to block incoming Web traffic to prevent users from running their own Web servers.

After analyzing your needs and the available solutions, it is not uncommon to find a clear winner. For those people fortunate enough to have multiple viable solutions, monthly cost and data speeds should be the deciding factors.

## SUMMARY

By focusing on how data communications devices of any type deliver on pre-determined business requirements and objectives, one can avoid purchasing technology that may be appealing or cleverly marketed, but which lacks the ability to deliver a positive impact on business objectives.

LAN media can differ significantly in cost, supported speeds, ease of use, and network architectures supported. Although fiber optic cable was at one time considered to be the only media suitable for speeds of 100Mbps and greater, Category 5 Unshielded Twisted Pair seems to be a common media option for high speed network standards. New advanced testing techniques have been developed to assure that UTP will be capable of transmitting high speed network architectures such as Gigabit Ethernet.

Point-to-point data communication occurs in either a serial or parallel manner. Modern connections are almost exclusively serial in nature. Common standards include RS-232, universal serial bus (USB) and IEEE-1394 (Firewire).

Using the transmission of data between a computer and the Internet as an example of a simple data communications system, many key concepts from last chapter were show in context in this chapter. These technologies include dial-up modems, digital subscriber line modems, and cable modems.

Current modem standards include V.34 and V.90. V.34 is the newest analog modem standard offering transmission speeds up to 33.6 Kbps in both directions. V.90 is a hybrid analog/digital standard that offers an asymmetrical transmission rate of up to 56 Kbps from a remote server to the modem and up to 33.6 Kbps from the modem to the server.

Current modulation standards such as V.34 and V.90 can deliver even more throughput over dial-up lines when compression standards such as MNP5 or V.42bis are applied. As this increasing sophistication in dial-up modems has yielded ever faster transmission speeds over dial-up lines, the types of network services offered by carriers have also evolved.

Regardless of the modem technology used dial-up data calls have limited data carrying capacity. To access the power of the Internet a faster means of connecting is required. Often referred to as broadband, these faster connections currently use two basic technologies: DSL and Cable modems.

Digital subscriber line (DSL) technologies use frequency division multiplexing to add a high speed data signal to the existing telephone local loop. The data is modulated and multiplexed in a DSL modem that is connected directly to the telephone wiring in the home. At the central office the signals are de-multiplexed by a DSL access multiplexer (DSLAM). DSL offers data speed in excess of 1 Mbps over an existing direct connection to the home.

Cable modem technologies use frequency division multiplexing to add high a high speed data signal to the existing cable television cable coming into the home. Similar to DSL, a cable modem handles the modulation/demodulation at the home and a cable modem termination system (CMTS) handles it at the cable head end. However, unlike DSL the cable modem communication channel is shared among all of the users on the cable node.

New Internet access technologies such as fixed point wireless and 3G digital cellular systems promise to further improve the availability of high speed data connectivity to the home.

## KEY TERMS

physical layer  
four conductor station wire  
RYGB  
flat gray modular  
unshielded twisted pair

UTP  
EIA/TIA 568  
Attenuation  
Near-End Crosstalk (NExT)  
Powersum Crosstalk

Multimode  
Multimode Step Index Fiber  
Multimode Graded Index Fiber  
single mode  
DTE (data terminal equipment)

DCE (data communications equipment)	Bandwidth	Forward error correction
data circuit terminating equipment	Handshaking	Trellis coded modulation (TCM)
UART (Universal Asynchronous Receiver Transmitter)	Turnaround time	Convolutional encoding
universal serial bus (USB)	Echo cancellation	Link access protocol for modems (LAP-M)
IEEE-1394	Digital signal processors	Broadband
Firewire	DSP	Digital subscriber line (DSL)
i-Link	V.90	Asymmetrical digital subscriber line (ADSL)
IrDA	V.34	Digital subscriber line access multiplexer (DSLAM)
Bluetooth	V.42	Splitter
ISP	Quantization noise	Media filter
Internet Service Provider	Asymmetrical transmission	Cable modem termination system (CMTS)
POTS	V.42 bis	Diplexer
Plain Old Telephone Systems	MNP Class 5	DOCSIS
Public Switched Telephone Network	Repeater	Data over cable service interface specification
PSTN	Amplifier	Fixed point wireless
Dial-up line	Adaptive protocols	
Circuit-switched connection	Adaptive size packet assembly	
	MNP Class 4	
	Dynamic speed shifts	
	MNP Class 10	

## REVIEW QUESTIONS

- How can the top down model remain useful given the rate of rapidly changing technology?
- Why is twisted pair twisted?
- What is the importance of EIA/TIA 568?
- What is the most common type category of UTP installed today and why?
- Why is UTP category 5 favored over shielded twisted pair, coax, and fiber optic cable for many high speed network architectures?
- Why is shielded twisted pair considered trickier to install than UTP?
- What is the difference between powersum crosstalk and pair-to-pair crosstalk?
- How are Levels 5, 6, and 7 different from Category 5?
- Why are testing and certification specifications required beyond CAT 5?
- What are the key advantages of fiber optic media over copper media?
- List the two main types of fiber optic media and the advantages of each.
- List the 10 most commonly used RS-232 pins including name, abbreviation, and DCE/DTE orientation.
- What is the name of the device employed to monitor and manipulate RS-232 signals?
- At what speeds does USB operate?
- List three advantages of USB over RS-232.
- List the currently available versions of USB and the maximum data speeds offered by each.
- Differentiate between IEEE-1394, Firewire, and i.Link.
- At what speeds does IEEE-1394 operate?
- What is currently the primary application for IEEE-1394?
- List the currently available versions of IEEE-1394 and the maximum data speeds offered by each.
- Which point-to-point serial transmission standards offer power to attached devices?
- What is modulated to provide wireless connectivity via IrDA?
- What are some of the significant limitations associated with IrDA?
- Which IrDA standard offers multi-point communication?
- What is the size and data transmission speed offered by Bluetooth?
- What type of radio frequency communication does Bluetooth use?
- What is a piconet?
- What types of devices are likely to include Bluetooth capability?
- What is the purpose of the I-P-O model and how can it be used to model both ends of given circuit?
- What is an Internet service provider (ISP)? What types of services does an ISP provide?
- What is the potential throughput of a V.34 modem with V.42bis data compression?
- Why are standards important when it comes to data compression?

33. What is meant by an adaptive protocol? Give at least two examples.
34. What are the key differences between V.32 and V.32bis?
35. What does "bis" stand for?
36. What is the difference between V.42 and V.42bis?
37. How does a V.90 modem system overcome the 33.6 Kbps limit as dictated by Shannon's Law?
38. What is quantization error?
39. Explain why V.90 is asymmetrical in nature?
40. How fast can a V.90, 56 Kbps modem actually transfer data?
41. Will a V.90 modem provide faster speeds than a V.34 modem in all cases? Why or why not?
42. What are the major differences between repeaters and amplifiers?
43. Explain the differences between hardware and software flow control.
44. What is forward error correction and what is the trade-off involved in such a protocol?
45. Differentiate between MNP5 and V.42bis.
46. Differentiate between MNP4 and V.42
47. What are the main applications of dial-up Internet access today?
48. What does the term broadband mean in the context of Internet access?
49. What existing communication link into the home does DSL use?
50. What piece of equipment is required at the central office to enable DSL use?
51. What are the maximum speeds and distance limitations of the most commonly available DSL services?
52. Why are splitters or media filters required in DSL implementations?
53. What is the difference between consumer and business class DSL offerings?
54. Is DSL a shared or dedicated connection into the home?
55. What type of multiplexing is used by a cable modem?
56. In a cable modem deployment how many television channels are eliminated to provide bi-directional data services?
57. What piece of equipment is required at the cable system head end to enable cable modem usage?
58. Is cable modem access a shared or dedicated connection to the home?
59. What is a cable node and what is its relevance to cable modem services?
60. What is a diplexer and what is its purpose in a cable modem installation?
61. What is DOCSIS and why is it important?
62. What are the technologies developed to improve security in a cable modem deployment?
63. What are the three most common form factors for a cable modem? List the advantages of each.
64. Which offers higher data rates: DSL or cable modems?
65. What is fixed-point wireless and where is it initially being deployed?