Business Data Communications & Networking:

12th Edition

Chapter 3

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PHYSICAL LAYER

- The physical layer (also called layer 1) is the ***physical*** connection between the computers and/or devices in the network.
- This chapter examines how the physical layer operates.
- It describes the most commonly used media for network circuits and explains the **basic** technical concepts of how data are actually transmitted through the media.
- Three different types of transmission are described:
  - digital transmission of digital computer data
  - analog transmission of digital computer data, and
  - digital transmission of analog voice data.
- You ***do not need*** an engineering-level understanding of the topics to be an effective user and manager of data communication applications.
- It is important, however, that you understand the basic concepts, so this chapter is somewhat technical.

LESSON OBJECTIVES

- Be familiar with the different types of network circuits and media
- Understand
  - digital transmission of digital data
  - analog transmission of digital data
  - digital transmission of analog data
- Be familiar with
  - analog and digital modems
  - with multiplexing

3.1 INTRODUCTION

- The physical layer is the network hardware, including servers, clients, and circuits.
- In this chapter, we focus on the circuits and on how clients and servers transmit data through them.
- The circuits are usually a combination of physical media (e.g., cables, wireless transmissions) and special-purpose ***devices*** such as switches and routers that enable the transmissions to travel through the media.
- The word circuit has two very different meanings in networking, and sometimes it is hard to understand which meaning is intended.
  - **Sometimes, we use the word circuit to refer to the physical circuit**—the actual wire—used to connect two devices (physical media) that carry the message we transmit, such as the twisted pair wire used to connect a computer to the LAN in an office.
  - **In other cases, we are referring to a logical circuit used to connect two devices**, which refers to the transmission characteristics of the connection, such as when we say a company has a T1 connection to the Internet. In this case, T1 refers not to the physical media (i.e., what type of wire is used) but rather to how fast data can be sent through the connection.
- A T1 Connection is **an Internet connection providing high speed T1 bandwidth of 1.544Mbps delivered over fiber optic or copper phone lines.**

3.1 INTRODUCTION (contd).

- There are **two fundamentally different types of data** that can flow through the circuit: **digital and analog**.
- **Computers produce digital data** that are binary, either 0 or 1.
- In contrast, **telephones produce analog data** whose electrical signals are shaped like the sound waves they transfer; they can take on any value in a wide range of possibilities, not just 0 or 1.
- Data can be transmitted through a circuit in the same form they are produced.
  - Most computers, for example, transmit their digital data through digital circuits to printers and other attached devices.
  - Likewise, analog voice data can be transmitted through telephone networks in analog form.
- Data can be converted from one form into the other for transmission over network circuits.
  - For example, digital computer data can be transmitted over an analog telephone circuit using a modem.
- **A modem at the sender's computer translates the computer's digital data into analog data** that can be transmitted through the voice communication circuits, and a second modem at the receiver's end does the reverse.

3.1 INTRODUCTION (contd).

- **Likewise, it is possible to translate analog voice data into digital form for transmission over digital computer circuits using a device called a *codec*.**
- ***Once again, there are two codecs, one at the sender's end and one at the receiver's end*.**
- Why bother to translate voice into digital?
  - The answer is that digital transmission is "better" than analog transmission.
  - Specifically, digital transmission offers **five key benefits** over analog transmission. Digital transmission:
    - produces **fewer errors** than analog transmission. And it is easier to detect and correct errors.
    - permits **higher maximum transmission rates**. Fiber-optic cable, for example, is designed for digital transmission.
    - **is more efficient**. It is possible to send more data through a given circuit using digital rather than analog transmission.
    - is **more secure** because it is easier to encrypt.
    - Finally, and most importantly, **integrating voice**, **video**, and **data on the same circuit is far simpler with digital transmission**.

3.1 INTRODUCTION (contd).

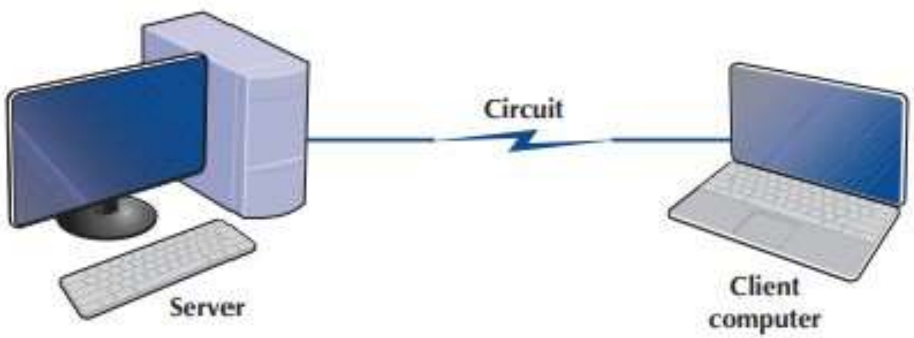
- Regardless of whether digital or analog transmission is used, transmission requires the **sender and receiver to agree on two key parameters.**
  - **First, they have to agree on the symbols that will be used: What pattern of electricity, light, or radio wave will be used to represent a 0 and a 1?**
  - Once these symbols are set, the sender and receiver have to agree on the **symbol rate**: How many symbols will be sent over the circuit per second?

- Analog and digital transmissions are different, but both require a commonly agreed on a set of symbols and a symbol rate.

3.2.1 Circuit Configuration

- Circuit configuration is the basic physical **layout** of the circuit.
  - There are two fundamental circuit configurations:
    - **point-to-point and multipoint**. Both are in practices.
- In practice, most complex computer networks have many circuits, some of which are point-to-point and some of which are multipoint.

FIGURE 3-1
Point-to-point circuit



3.2.1 Point-to-Point

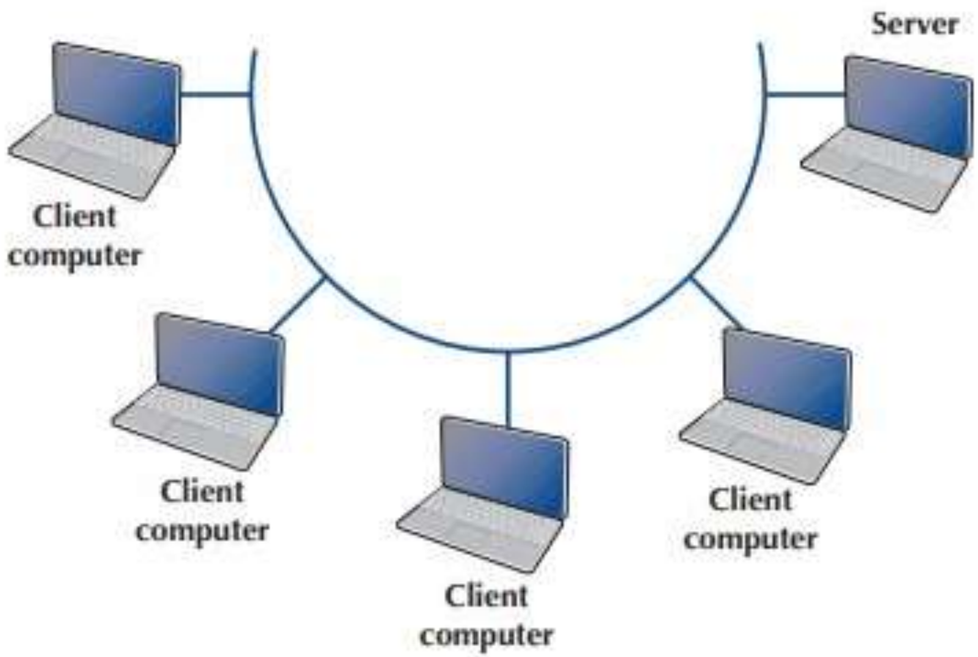
- Figure 3-1 illustrates a point-to-point circuit, which is so named because it goes from one point to another (e.g., one computer to another computer).
- These circuits sometimes are called ***dedicated*** circuits because they are dedicated to the use of these two computers.
- **This type of configuration is used when the *computers generate enough data to fill the capacity of the communication circuit*.**
- When an organization builds a network using point-to-point circuits, *each computer has its own circuit running from itself to the other computers*.
- This can get **very expensive**, particularly if there is some ***distance*** between the computers.
- Despite the cost, point-to-point circuits are used regularly in modern wired networks to connect
  - clients to switches
  - switches to switches and routers, and
  - routers to routers.

We will discuss these circuits in detail in Chapter 7.

3.2.1 Multipoint Circuit

- Figure 3-2 shows a multipoint circuit (also called a ***shared*** circuit, many computers are connected on the same circuit).
- This means that each must share the circuit with the others. **The disadvantage is that only one computer can use the circuit at a time.**
- When one computer is sending or receiving data, all others must **wait**.
- The advantage of multipoint circuits is that they reduce the ***amount of cable (cost)*** required and typically use the available communication circuit more efficiently.
- Imagine the number of circuits that would be required if the network in Figure 3-2 were designed with separate point-to-point circuits.
- For this reason, multipoint configurations are **cheaper** than point-to-point circuits.
- Thus, multipoint circuits typically are used when
  - each computer does not need to **continuously** use the entire capacity of the circuit or
  - when building point-to-point circuits is too expensive.
- **Wireless circuits are mostly multipoint circuits** because multiple computers use the same radio frequencies **and must take turns** transmitting

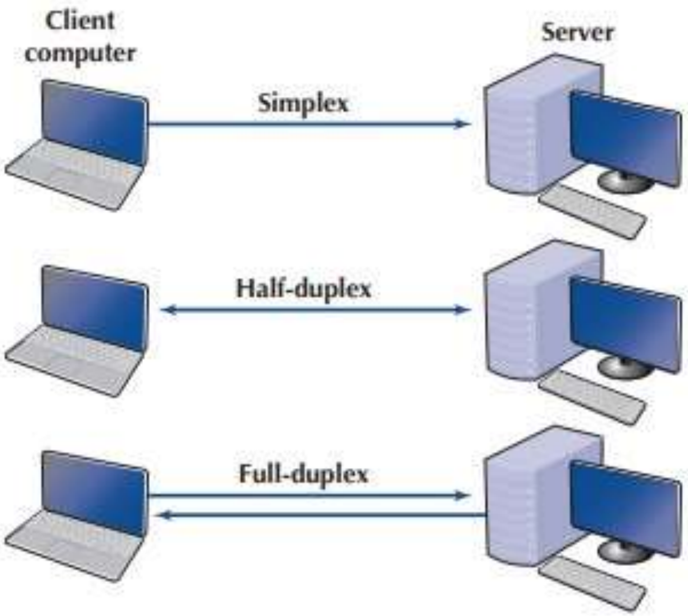
FIGURE 3-2
Multipoint circuit



3.2.2 Data Flow

- Circuits can be designed to permit data to flow in one direction or in both directions.
- There are three ways to transmit:
  - Simplex (one-way transmission, such as that with radios and TVs)
  - Half-duplex, and
  - Full-duplex

FIGURE 3-3
Simplex, half-duplex, and full-duplex transmissions



3.2.2 Data Flow (contd).

- A half-duplex communication link is similar to a **walkie-talkie** link;
  - only one computer can transmit at a time.
  - **Computers use control signals to negotiate which will send and which will receive data.**
  - The amount of time half-duplex communication takes to switch between sending and receiving is called **turnaround** time (also called **retrain** time or **reclocking** time).
  - The turnaround time for a specific circuit can be obtained from its technical specifications (often between 20 and 50 milliseconds).
  - With full-duplex transmission, you can transmit in both directions simultaneously, with ***no turnaround time***.

3.2.2 Data Flow (contd).

- **How do you choose which data flow method to use**?
- Obviously, one factor is the **application**. If data always need to flow only in one direction (e.g., from a remote sensor to a host computer), then simplex is probably the best choice.
- In most cases, however, data must flow in ***both*** directions.
- The initial temptation is to presume that a full-duplex channel is best; however, each circuit has only so much capacity to carry data.
- **Creating a full-duplex circuit means that the circuit offers full capacity both ways simultaneously.**
- In some cases, it makes more sense to build a set of simplex circuits in the same way a set of one-way streets can increase the speed of traffic.
- In other cases, a half-duplex circuit may work best. For example, terminals connected to mainframes often transmit data to the host, wait for a reply, transmit more data, and so on, in a turn-taking process; usually, traffic does not need to flow in both directions simultaneously.
- Such a traffic pattern is ideally suited to half-duplex circuits

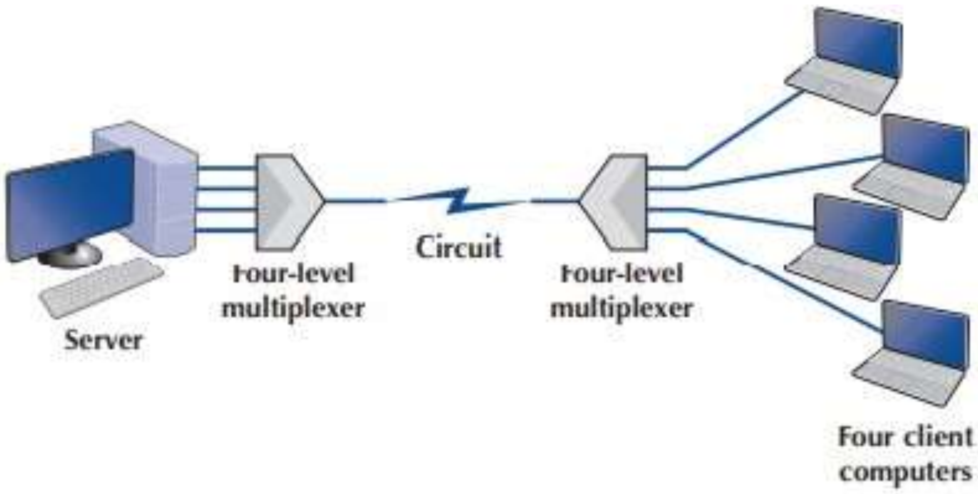
3.2.3 Multiplexing

- **Multiplexing means ‘to break one high-speed physical communication circuit into several lower-speed logical circuits’ so that many different devices can simultaneously use it but still “think” that they have their own separate circuits (the multiplexer is “transparent”).**
- Without multiplexing, the Internet would have collapsed in the 1990s.
- Multiplexing often is done in multiples of 4 (e.g., 8, 16).
- Figure 3-4 shows a four-level multiplexed circuit.
- Note that two multiplexers are needed for each circuit: one to combine the four original circuits into the one multiplexed circuit and one to separate them back into the four separate circuits.
- Benefit is to **save money by reducing the amount of cable or the number of network circuits** that must be installed.
- For example, if we did not use multiplexers in Figure 3-4, we would need to run four separate circuits from the clients to the server.
- If the clients were located close to the server, this would be inexpensive.
- However, if they were located miles away, the costs could be substantial.

3.2.3 Multiplexing (contd).

- There are **four** types of multiplexing: (1) frequency division multiplexing (FDM), (2) time division multiplexing (TDM), (3) statistical time division multiplexing (STDM), and (4) wavelength division multiplexing (WDM).

FIGURE 3-4
Multiplexed circuit



3.2.3 Multiplexing (contd).

- **FDM** can be described as dividing the circuit “horizontally” so that many signals can travel a single communication circuit simultaneously.
- The circuit is divided into a series of separate channels, each transmitting on a different frequency, much like a series of different radio/TV stations.
- All signals exist in the media simultaneously, ***but because they are on different frequencies, they do not interfere with each other***.
- **TDM** shares a communication circuit among two or more computers by having them take turns, dividing the circuit vertically, so to speak.
- **STDM** is the exception to the rule that the *capacity of the multiplexed circuit must equal the sum of the circuits it combines*.

3.2.3 Multiplexing (contd)

- **STDM allows more terminals/computers to be connected to a circuit than does FDM or TDM**.
- Example: If you have four computers connected to a multiplexer and each can transmit at 64 Kbps, then you should have a circuit capable of transmitting 256 Kbps (4 × 64 Kbps).
  - However, not all computers will be transmitting continuously at their maximum transmission speed.
  - Users typically pause to read their screens or spend time typing at lower speeds.
- Therefore, you do not need to provide a speed of 256 Kbps on this multiplexed circuit.
  - If you assume that only two computers will ever transmit at the same time, 128 Kbps will be enough.
  - STDM is called **statistical** because ***the selection of transmission speed*** for the multiplexed circuit is based on a statistical analysis of the usage requirements of the circuits to be multiplexed.

3.2.3 Multiplexing (contd)

- WDM is a version of FDM used in fiber-optic cables.
- **When fiber-optic cables were first developed, the devices attached to them were designed to use only one color of light generated by a laser or LED.**
- **Light has different frequencies (i.e., colors), so rather than building devices to transmit using only one color, why not send multiple signals, each in a different frequency, through the same fiber-optic cable?**
- By simply attaching different devices that could transmit in the full spectrum of light rather than just one frequency, the capacity of the existing fiber-optic cables could be dramatically increased, with no change to the physical cables themselves.

3.2.3 Multiplexing (contd).

- One technology that you may have come across that uses multiplexing is ***DSL (digital subscriber line),*** and it allows for simultaneous transmission of
  - voice (phone calls)
  - data going to the Internet (called upstream data), and
  - data coming to your home from the Internet (called downstream data).
- You need a **DSL Modem**.
- With DSL, a DSL modem is installed at the customer's home or office, and another DSL modem is installed at the telephone company switch closet.
- The modem is first an FDM device that splits the physical circuit into three logical circuits (phone, upstream data, and downstream data).
- TDM is then used within the two data channels to provide a set of one or more individual channels that can be used to carry different data.
- **A combination of amplitude and phase *modulation*** is used in the data circuits to provide the desired data rate.

You will learn more about DSL in Chapter 10.

MF 3-1 Structure Cabling EIQ/TIA 568-B

- In 1995, the Telecommunications Industry Association (TIA) and Electronic Industries Alliance (EIA) came up with the first standard to create structured cabling, called **TIA/EIA 568-A.**
- This standard defined the minimum requirements for internal telecommunications wiring within buildings and between buildings
- This standard was updated and changed many times, and today the accepted standard is TIA/EIA 568-B, which came out in **2002**.
- This standard has **six** subsystems.

MF 3-1 Structure Cabling EIQ/TIA 568-B (contd).

- This standard has six subsystems:
  1. **Building entrance**: the point where external cabling and wireless connects to the internal building wiring and equipment room.
  2. **Equipment room (ER)**: the room where network servers and telephone equipment would be stored.
  3. **Telecommunications closet:** the room that contains the cable **termination** points and the distribution frames
  4. **Backbone cabling:** the cabling that interconnects telecommunication closets, equipment rooms, and building entrances **within a building**; also, this refers to cabling between buildings
  5. **Horizontal cabling:** the cabling that runs from the **telecommunications closet to each LAN**
  6. **Work area:** the cabling where the computers, printers, patch cables, jacks, and so on are located

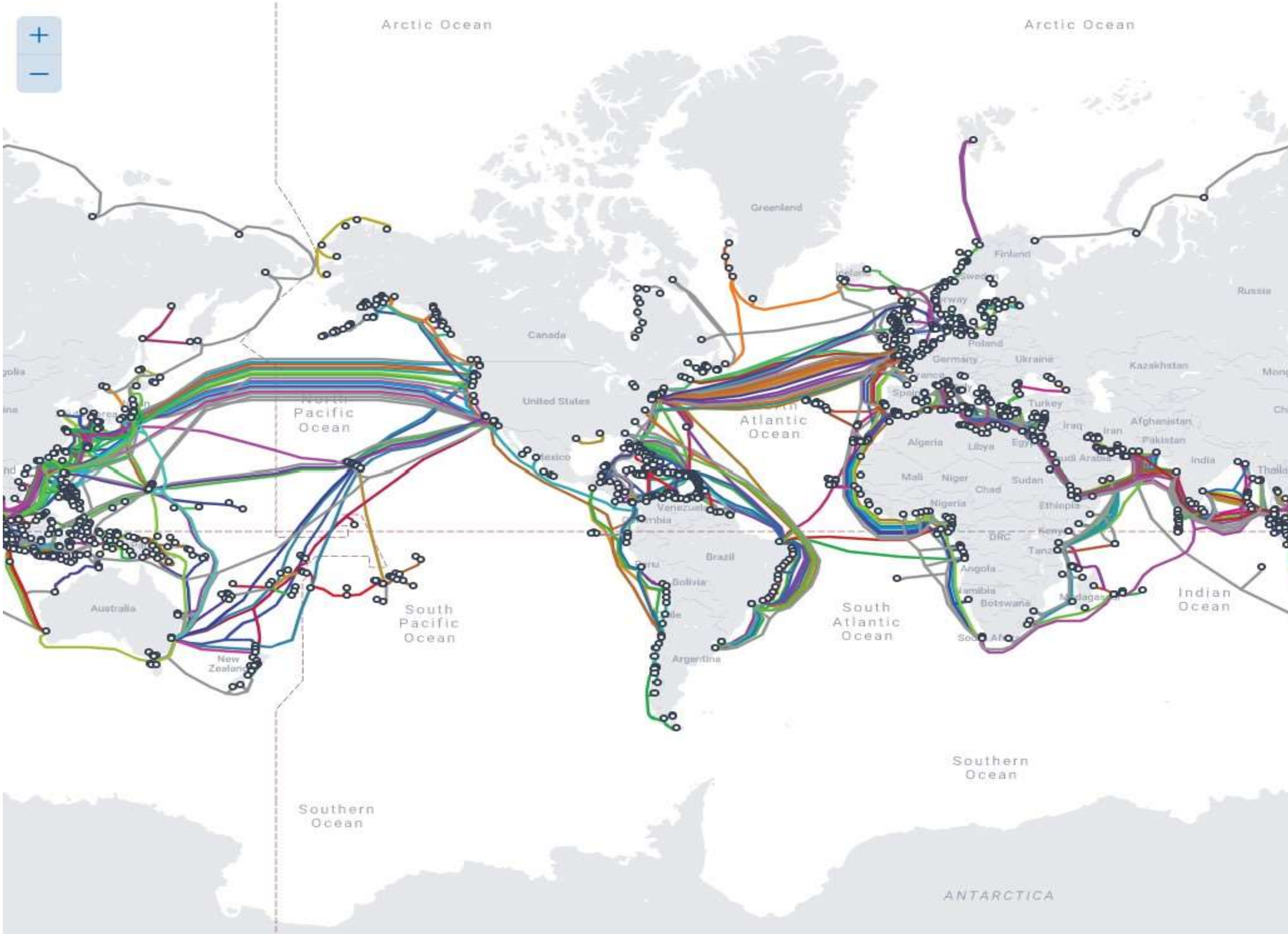
This standard describes what the master cabling document should look like (which would describe each of the six points discussed previously) and applies to both twisted pair and fiber-optic cabling

MF 3-2 Undersea Fiber-Optic Cables

- What happens when you send an email from the United States to Europe?
- How is your email transmitted from one continent to another?
- It most likely travels through one of the ***submarine cables*** that connect America and Europe.
- A neat interactive submarine cable map can be found at http://www.submarinecablemap.com.
- This map shows each cable's name, ready-for-service (RFS) date, length, owners, website (if any), and landing points.
- Each cable on this map has a capacity of at least 5 Gbps.
- The first submarine telecommunication cable was laid in the 1850s and carried **telegraphy** traffic.
- ***Today, we use the fiber-optic cable that carries phone, Internet, and private data as digital data.***

MF 3-2 Undersea Fiber-Optic Cables (contd).

- How do these cables get laid on the seabed?
  - Submarine cables are laid using **special cable-layer ships**—these factories produce the cable on board and have the equipment to lay and bury the cable.
  - The cable-layer ships get as close as possible to the shore where the cable will be connected.
  - A messenger line is sent out from the ship using a work boat that takes it to the shore.
  - Once the cable is secured on shore, the installation process under the sea can begin.
  - A 30-ton sea plow with the cable in it (think about a needle and thread) is then tossed overboard and lands on the seabed.
  - The plow then buries the cable under the sea bed at a required burial depth (up to 3 meters).
  - The simultaneous lay-and-bury of the cable continues until an agreed position, after which the cable is surface laid until reaching its destination.



Arctic Ocean
Arctic Ocean
Greenland
Canada
United States
Pacific
Ocean
Atlantic
Ocean
Finland
Russia
Kazakhstan
Ukraine
Poland
Germany
Turkey
Iraq
Iran
Afghanistan
Pakistan
India
Algeria
Libya
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
DRC
Angola
Botswana
Brazil
Bolivia
Argentina
Australia
South
Pacific
Ocean
South
Atlantic
Ocean
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Ocean
Southern
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3.3 Communications Medium or Media (if there is more than one)

- The medium or media is the **physical matter** or substance that carries the voice or data transmission.
- Many different types of transmission media are currently in use, such as:
  - **copper (wire),**
  - **glass or plastic (fiber-optic cable), or**
  - **air (radio, microwave, or satellite).**
- There are two basic types of media. **Guided** media are those in which the message flows through a physical medium such as a twisted pair wire, coaxial cable, or fiber-optic cable; **the medium "guides" the signal**.
- **Wireless media are those in which the message is broadcast through the air, such as microwaves or satellites.**
- In many cases, the circuits used in WANs are provided by the various common carriers who sell usage of them to the public.
- We call the circuits sold by the common carriers ***communication services***.
- The following sections describe the medium and the basic characteristics of each circuit type.
- If your organization has leased a circuit from a common carrier, you are probably less interested in the media used and more interested in whether the speed, cost, and reliability of the circuit meet your needs.

3.3.1 Twisted Pair

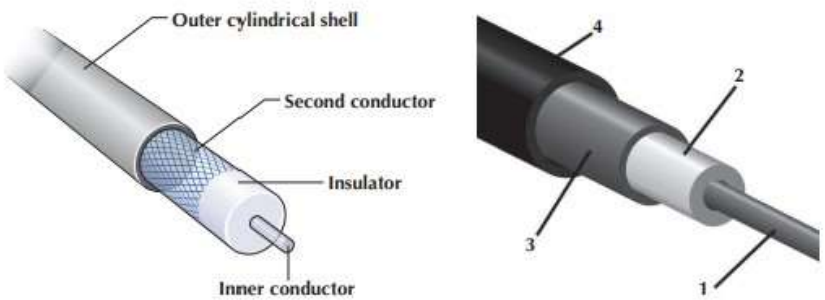
- One of the most commonly used types of guided media is **twisted pair cable.**
- Insulated pairs of wires are packed quite close together (Figure 3-5).
- The wires usually are twisted to minimize the ***electromagnetic interference between one pair and any other pair in the bundle***.
- Your house or apartment probably has a set of two twisted pair wires (i.e., four wires) from it to the telephone company network.
- One pair is used to connect your telephone; the other pair is a spare that can be used for a second telephone line.
- The twisted pair cable used in LANs are usually packaged as **four** sets of pairs, as shown in Figure 3-5, whereas bundles of several thousand wire pairs are placed under city streets and in large buildings.
- The specific types of twisted pair cable used in LANs, such as **Cat 5e** and **Cat 6**, are discussed in Chapter 7

FIGURE 3-5
Category 5e twisted pair wire
Source: Courtesy of Belkin International, Inc.

3.3.2 Coaxial Cable

- Coaxial cable is a type of guided medium that is quickly disappearing.
- Coaxial cable has a copper core (the inner conductor) with an outer cylindrical shell for insulation.
- The outer shield, just under the shell, is the second conductor.
- Because they have additional shielding provided by their multiple layers of material, **coaxial cables are less prone to interference** and errors than basic low-cost twisted pair wires.
- Coaxial cables **cost about three** times as much as twisted pair wires but offer few additional benefits other than better shielding.
- One can also buy specially shielded twisted pair wire that provides the same level of quality as coaxial cable but at half its cost.
- For this reason, few companies are installing coaxial cable today, although some still continue to use existing coaxial cable that was installed years ago.

FIGURE 3-6
Coaxial cables. Thinnet and Thicknet Ethernet cables (right) - 1. center core, 2. dielectric insulator, 3. metallic shield, 4. plastic jacket and cross-sectional view (left)
Source: Courtesy of Tim Kloske



3.3.3 Fiber-Optic Cable

- Although twisted pair is the most common type of guided medium, fiber-optic cable also is becoming widely used.
- Instead of carrying telecommunication signals in the traditional electrical form, this technology uses high-speed streams of **light pulses** from lasers or LEDs (light-emitting diodes) that carry information inside hair-thin strands of glass called optical fibers.
- Figure 3-7 shows a fiber-optic cable and depicts the optical core, the cladding (metal coating), and how light rays travel in optical fibers.
- The earliest fiber-optic systems were **multimode, meaning that the light could reflect inside the cable at many different angles.**
- **Multimode cables are plagued by excessive signal weakening (attenuation) and dispersion (spreading of the signal so that different parts of the signal arrive at different times at the destination).**
- For these reasons, early multimode fiber was usually limited to about 500 meters.
- **Graded-index multimode fiber** attempts to reduce this problem by changing the refractive properties of the glass fiber so that as the light approaches the outer edge of the fiber, it speeds up, which compensates for the slightly longer distance it must travel compared with light in the center of the fiber.

3.3.3 Fiber-Optic Cable (contd).

- Therefore, the light in the center is more likely to arrive at the same time as the light that has traveled at the edges of the fiber.
- This increases the effective distance to just under 1,000 meters.
- *Single-mode fiber-optic cables* transmit a single direct beam of light through a cable that ensures the light reflects in only one pattern, in part because the core diameter has been reduced from 50 microns to about 5 to 10 microns.
- This smaller-diameter core allows the fiber to send a more concentrated light beam, resulting in faster data transmission speeds and longer distances, often up to 100 kilometers.
- However, because the light source must be perfectly aligned with the cable, single-mode products usually use lasers (rather than the LEDs used in multimode systems) and therefore are more expensive.

3.3.3 Fiber-Optic Cable (contd).

- Fiber-optic technology is a revolutionary departure from the traditional copper wires of twisted pair cable or coaxial cable.
- One of the main advantages of fiber optics is that it can carry **huge amounts of information at extremely fast data rates**. This capacity makes it ideal for the simultaneous transmission of voice, data, and image signals.
- In most cases, fiber-optic cable
  - works better under harsh environmental conditions than do its metallic counterparts.
  - It is not as fragile or brittle, it is not as heavy or bulky, and it is more resistant to corrosion.
  - Also, in case of fire, an optical fiber can withstand higher temperatures than can copper wire.
  - Even when the outside jacket surrounding the optical fiber has melted, a fiber-optic system still can be used.

3.3.4 Radio

- One of the most commonly used forms of wireless media is ***radio***; when people used the **term wireless, they usually mean radio transmission.**
- When you connect your laptop to the network wirelessly, you are using radio transmission.
- Radio data transmission uses the same basic principles as standard radio transmission.
- Each device or computer on the network has a ***radio receiver/transmitter*** that uses a specific frequency range that does not interfere with commercial radio stations.
- **The transmitters are very low power, designed to transmit a signal only a short distance, and are often built into portable computers or handheld devices such as phones and personal digital assistants.**

Wireless technologies for LAN environments, such as IEEE 802.1x, are discussed in more detail in Chapter 7

3.3.5 Microwave

- Microwave transmission is an extremely high-frequency radio communication beam that is transmitted over a direct ***line-of-sight path*** between any two points.
- As its name implies, a microwave signal is an extremely short wavelength, thus the word micro-wave.
- **Microwave radio transmissions perform the same functions as cables.**
- For example, point A communicates with point B via a through-the-air microwave transmission path, instead of a copper wire cable.
- Because microwave signals approach the frequency of visible light waves, they exhibit many of the same characteristics as light waves, such as reflection, focusing, or refraction.
- As with visible light waves, microwave signals can be focused into narrow, powerful beams that can be projected over long distances.
- Just as a parabolic reflector focuses a searchlight into a beam, a parabolic reflector also focuses a high-frequency microwave into a narrow beam.
- **Towers are used to elevate the radio antennas to account for the earth's curvature** and maintain a clear line-of-sight path between the two parabolic reflectors; see Figure 3-8.

3.3.5 Microwave (contd).

- This transmission medium is typically used for long-distance data or voice transmission.
- It does not require the laying of any cable, because long-distance antennas with microwave **repeater stations** can be placed approximately **25–50 miles apart.**
- A typical long-distance antenna might be **10 feet wide**, although over shorter distances in the inner cities, the dish antennas can be less than 2 feet in diameter.
- The airwaves in larger cities are becoming congested because so many microwave dish antennas have been installed that they interfere with one another

FIGURE 3-8

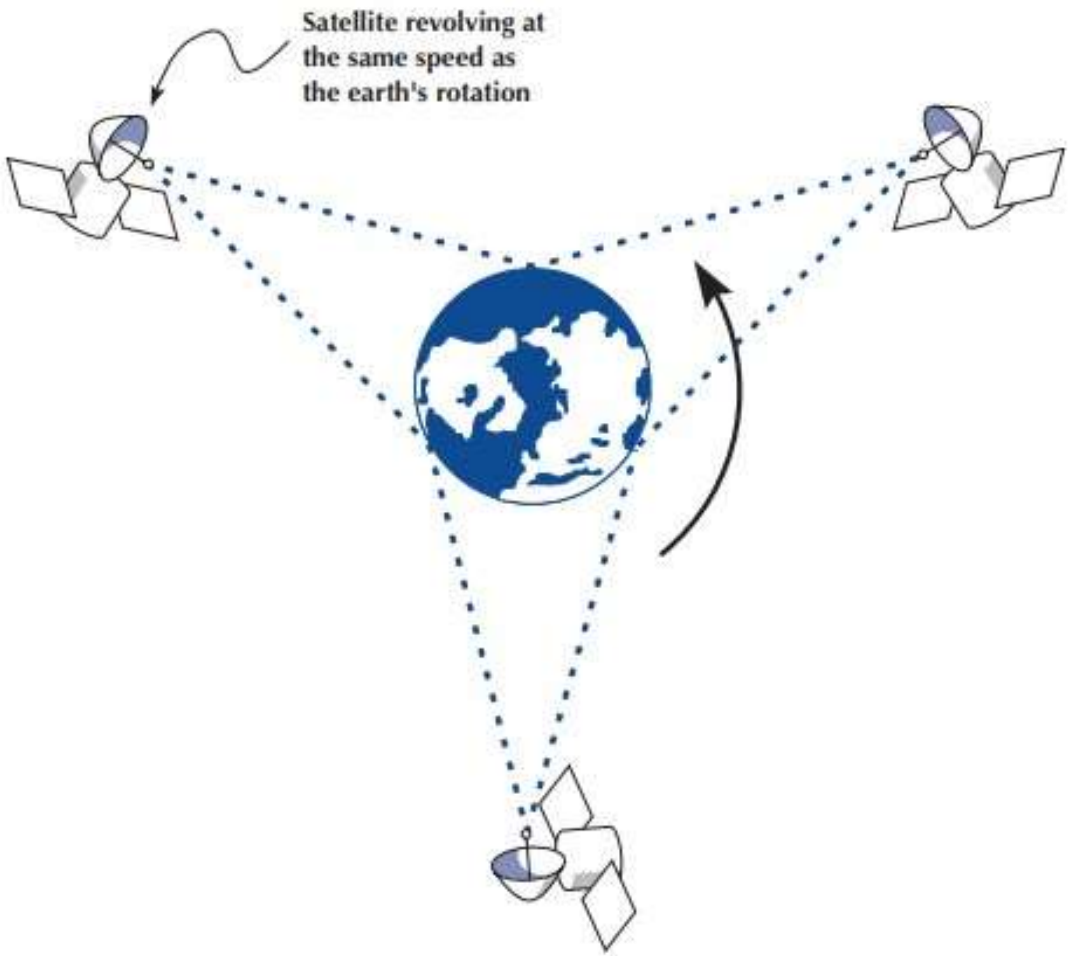
A microwave tower. The round antennas are microwave antennas and the straight antennas are cell phone antennas

Source: © Matej Pribelsky / iStockphoto

3.3.6 Satellite

- Satellite transmission is similar to microwave transmission,
- Except, instead of transmission involving another nearby microwave dish antenna, it involves a satellite many miles up in space.
- Figure 3-9 depicts a **geosynchronous** satellite.
- Geosynchronous means that the satellite remains stationary over one point on the earth. How?
- One disadvantage of satellite transmission is the **propagation delay** that occurs because the signal has to travel out into space and back to earth, a distance of many miles that even at the speed of light can be **noticeable**.
- Low earth orbit (LEO) satellites are placed in lower orbits to minimize propagation delay.
- Satellite transmission is sometimes also affected by ***raindrop attenuation*** when satellite transmissions are absorbed by heavy rain.
- It is not a major problem, but engineers need to work around it.

FIGURE 3-9
Satellites in operation



3.3.7 Media Selection

Which media are best? It is hard to say, particularly when manufacturers continue to improve various media products. Several factors are important in selecting media.

- **The type of network** is one major consideration. Some media are used only for WANs (microwaves and satellites), whereas others typically are not (twisted pair, coaxial cable, and radio), although we should note that some old WAN networks still use twisted pair cable. Fiber-optic cable is unique because it can be used for virtually any type of network.
- **Cost** is always a factor in any business decision. Costs are **always** changing and competition among vendors is driving prices down.
- Among the guided media, **twisted pair wire is generally the cheapest (why?)**, coaxial cable is somewhat more expensive, and **fiber-optic cable is the most expensive**.
- The cost of wireless media is generally driven more by distance than any other factor.
  - For very short distances (several hundred meters), radio is the cheapest;
  - for moderate distances (several hundred miles), microwave is cheapest; and
  - for long distances, satellite is cheapest.

3.3.7 Media Selection (contd).

- **Transmission Distance** is a related factor.
  - Twisted pair wire coaxial cable and radio can transmit data only a short distance before the signal must be **regenerated**.
  - Twisted pair wire and radio typically can transmit up to 100–300 meters, and coaxial cable typically between 200 and 500 meters.
  - Fiber optics can transmit up to 75 miles, and new types of fiber-optic cable can reach more than 600 miles.
- **Security** is primarily determined by whether the media are guided or wireless.
  - Wireless media (radio, microwave, and satellite) are the least secure because their signals are easily intercepted.
  - Guided media (twisted pair, coaxial, and fiber optics) are more secure
  - Fiber optics being the most secure.

3.3.7 Media Selection (contd).

- **Error Rates** (are also important)
  - Wireless media are most susceptible to interference and thus have the highest error rates.
  - Among the guided media, fiber optics provides the lowest error rates, coaxial cable the next best, and twisted pair cable the worst.
  - However, twisted pair cable is generally better than wireless media.
- **Transmission Speeds** vary greatly among the different media. It is difficult to quote specific speeds for different media because transmission speeds are constantly improving and because they vary within the same type of media, depending on the specific type of cable and the vendor.
  - In general,
    - Twisted pair cable and coaxial cable can provide data rates of between 1 Mbps and 1 Gbps.
    - Radio, microwave, and satellite generally provide 10–100 Mbps.
    - Fiber-optic cable ranges between 1 Gbps and 40 Gbps.

3.4 DIGITAL TRANSMISSION OF DIGITAL DATA

All computer systems produce binary data. For these data to be understood by both the sender and receiver, both must agree on a standard system for representing the letters, numbers, and symbols that compose messages. The coding scheme is the language that computers use to represent data

- **3.4.1 Coding:** ***What is a code?***
  - A *character* is a symbol that has a common, constant meaning.
  - A character might be the letter A or B, or it might be a number such as 1 or 2. Characters also may be special symbols such as &.
  - Characters in data communications, as in computer systems, are represented by groups of bits that are binary zeros (0) and ones (1).
  - The groups of bits representing the set of characters that are the "alphabet" of any given system are called a coding scheme, or simply a code.
  - A byte is a group of consecutive bits that is treated as a unit or character. One byte normally is composed of 8 bits and usually represents one character; however, in data communications, some ***codes*** use 5, 6, 7, 8, or 9 bits to represent a character. For example, the representation of the character '**A**' by a group of 8 bits (say, 01 000 001) is an example of coding.

3.4.1 Coding (contd).

- There are three predominant coding schemes in use today.
- American Standard Code for Information Interchange (**ASCII**) is the most popular.
- There are **two types of ASCII; 7-bit code that has 128, AND 8-bit code.**
- The number of combinations can be determined by taking the number 2 and raising it to the power equal to the number has two values, a 0 or a 1.
- In this case $2^7 = 128$ characters or $2^8 = 256$ characters.
- A second commonly used coding scheme is **ISO 8859**, which is an 8-bit code that includes the ASCII codes plus non-English letters used by many European languages (e.g., letters with accents).
- If you look closely at Figure 2.21, you will see that HTML often uses (character set) **ISO 8859.**
- **Unicode** is the other commonly used coding scheme. There are many different versions of Unicode.
  - UTF-8 is an 8-bit version very similar to ASCII.
  - UTF-16, which uses 16 bits per character (i.e., 2 bytes, called a “word”), is used by Windows.
- By using more bits, **UTF-16** can represent many more characters beyond the usual English or Latin characters, such as **Cyrillic** or **Chinese**

3.4.1 Coding (contd).

- **Unicode:**We can choose any pattern of bits we like to represent any character we like, as long as all computers understand what each bit pattern represents.
- Figure 3-10 below shows the 8-bit binary bit patterns used to represent a few of the characters we use in ASCII.

FIGURE 3-10
Binary numbers used to represent different characters using ASCII

Character	ASCII
A	01000001
B	01000010
C	01000011
D	01000100
E	01000101
a	01100001
b	01100010
c	01100011
d	01100100
e	01100101
1	00110001
2	00110010
3	00110011
4	00110100
!	00100001
$	00100100

3.4.2 Transmission Modes

- **Parallel**
  - Parallel transmission is the way the internal transfer of binary data takes place inside a computer. If the internal structure of the computer is 8 bit, then all 8 bits of the data element are transferred between main memory and the central processing unit(CPU) simultaneously on 8 **separate** connections.
  - The same is true of computers that use a 32-bit structure; all 32 bits are transferred simultaneously on 32 connections
- **Serial**
  - Serial transmission means that a stream of data is sent over a communication circuit **sequentially** in a bit-by-bit fashion.
  - In this case, there is only **one** physical wire inside the bundle, and all data must be transmitted over that one physical wire.
  - It takes n iterations or cycles to transmit n bits.
  - Thus, serial transmission is considerably slower than parallel transmission—eight times slower in the case of 8-bit ASCII (because there are 8 bits).

FIGURE 3-11
Parallel transmission of an 8-bit code

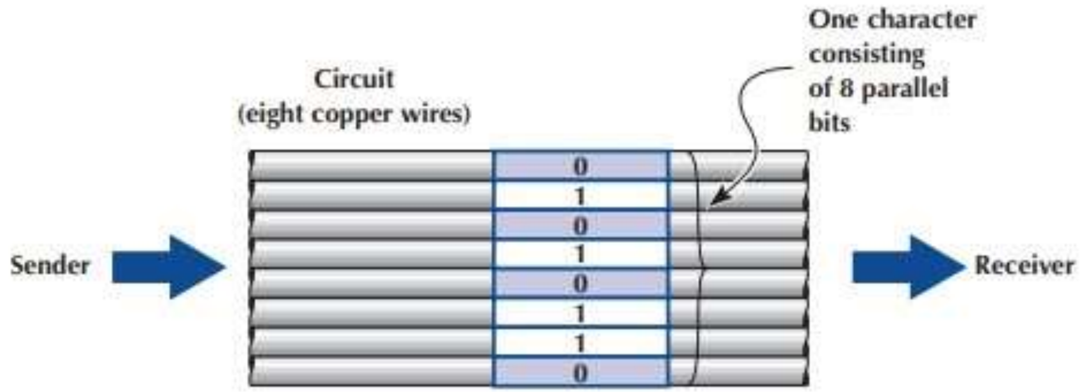
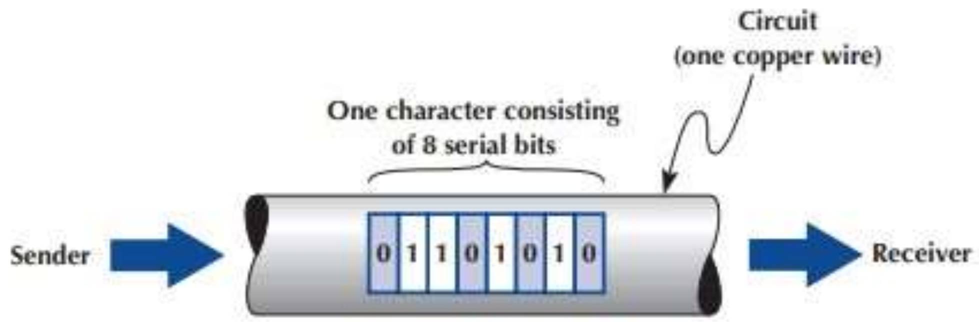


FIGURE 3-12
Serial transmission of an 8-bit code

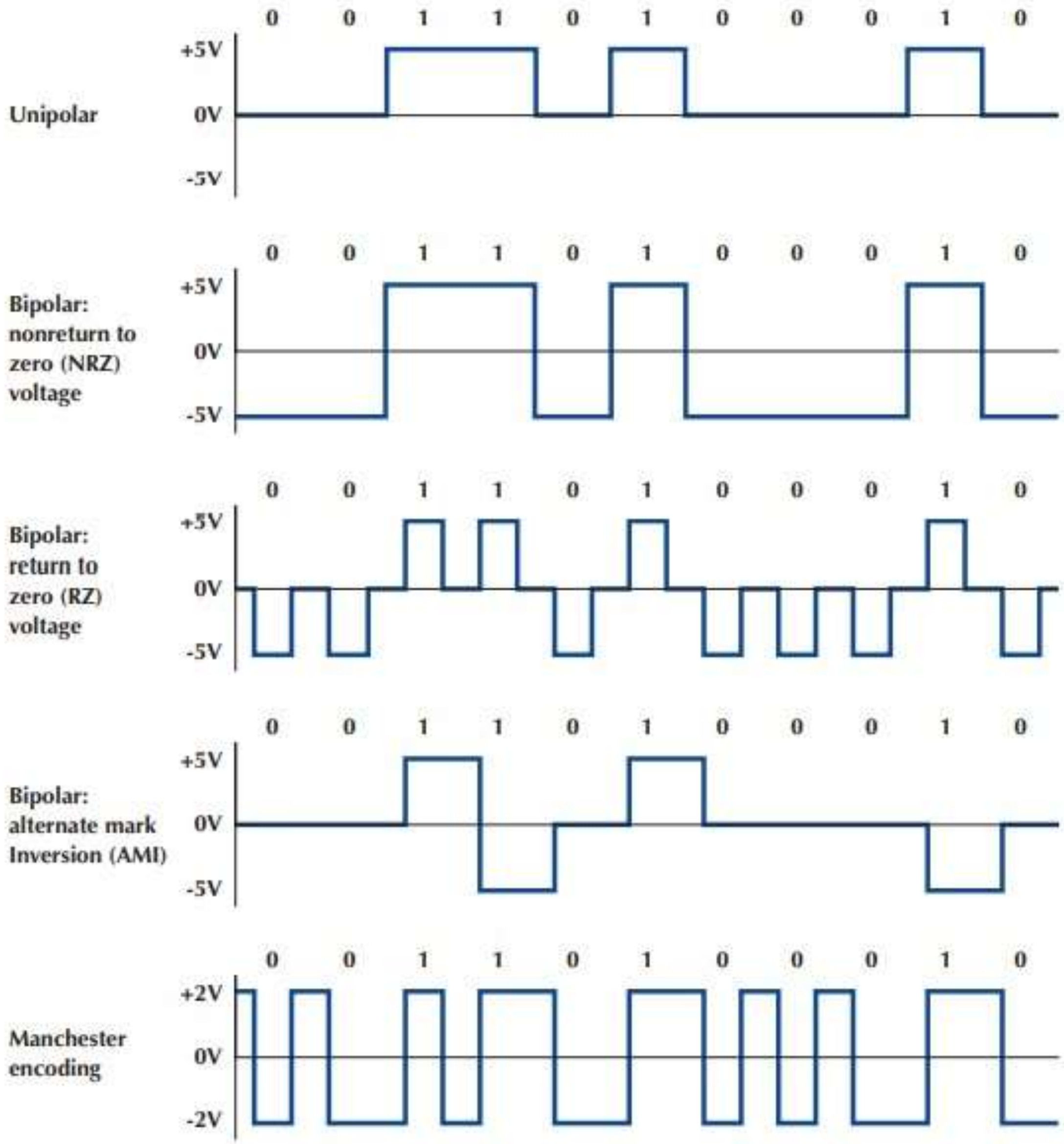


3.4.3 Digital Transmission

- **Digital** transmission is the transmission of binary electrical or light pulses in that it only has two possible states, a 1 or a 0.
- The most commonly encountered voltage levels range from a low of +3/−3 to a high of +24/−24 volts.
- Zero volts for bit ‘0’ and 5 volts for bit ‘1’ is another example.
- Digital signals are usually sent over a wire of **no more than a few thousand** feet in length.
- All digital transmission techniques require a set of symbols (to define how to send a 1 and a 0) and the symbol rate (how many symbols will be sent per second).

- Figure 3-13 shows five types of digital transmission techniques.
  - Unipolar
  - Bipolar NRZ (nonreturn to zero) voltage
  - Bipolar RZ (return to zero) voltage
  - Bipolar: Alternate Mark Inversion (AMI)
  - Manchester Encoding

FIGURE 3-13
Unipolar, bipolar, and Manchester signals (digital)



3.4.3 Digital Transmission (contd).

- Figure 3-13 shows five types of digital transmission techniques.
- Figure 3-13 illustrates a **unipolar** technique in which a signal of 0 volts (no current) is used to transmit a zero and a signal of +5 volts is used to transmit a 1.
- An obvious question at this point is this: If 0 volts means a zero, how do you send no data?
- For the moment, we will just say that there are ways to indicate when a message starts and stops, and when there are no messages to send, the sender and receiver agree to ignore any electrical signal on the line.
- To successfully send and receive a message, both the sender and receiver have to agree on how often the sender can transmit data—that is, on the **symbol rate**.
  - For example, if the symbol rate on a circuit is 64 Kilo Hertz (KHz) (64,000 symbols per second), then the sender changes the voltage on the circuit **once** every 1⁄64,000 of a second and the receiver must examine the circuit every 1⁄64,000 of a second to read the incoming data

3.4.3 Digital Transmission (contd).

- In **bipolar** signaling, the ones and zeros vary from a plus voltage to a minus voltage (like an AC).
- The first bipolar technique illustrated is called nonreturn to zero (NRZ) because the voltage alternates from +5 volts (a symbol indicating a 1) to−5 volts (a symbol indicating a 0) without ever returning to 0 volts.
- The second bipolar technique in this figure is called return to zero (RZ) because it always returns to 0 volts after each bit before going to +5 volts (the symbol for a 1) or −5 volts (the symbol for a 0).
- The third bipolar technique is called AMI because a 0 is always sent using 0 volts, but 1s alternate between +5 volts and −5 volts.
  - AMI is used on T1 and T3 circuits. In Europe, bipolar signaling sometimes is called double current signaling because you are moving between a positive and negative voltage potential.
- In general, bipolar signalling experiences fewer errors **(Why?)**
  - Noise (additive) or interference is less likely to cause the bipolar's +5 volts to be misread as −5 volts.
  - Also, because changing the polarity of a current (from positive to negative, or vice versa) is more difficult than changing its magnitude

3.4.4 How Ethernet Transmits Data?

- The most common technology used in LANs is Ethernet.
- If you are working in a computer lab on campus, you are most likely using Ethernet.
- Ethernet uses digital transmission over either serial or parallel circuits, depending on which version of Ethernet you use.
- One version of Ethernet that uses serial transmission requires 1/10,000,000 of a second to send one symbol; that is, it transmits 10 million symbols (each of 1 bit) per second.
- This gives a data rate of 10 Mbps, and if we assume that there are 8 bits in each character, this means that about 1.25 million characters can be transmitted per second in the circuit.
- Ethernet uses Manchester encoding, which is a special type of bipolar signaling in which:
    - The signal is changed from high to low or low to high in the middle of the signal.
    - A change from high to low represents a 0, whereas the opposite (a change from low to high) represents a 1.
    - Manchester encoding is less susceptible to errors going undetected because if there is no transition in the middle of the signal, the receiver knows that an error must have occurred.

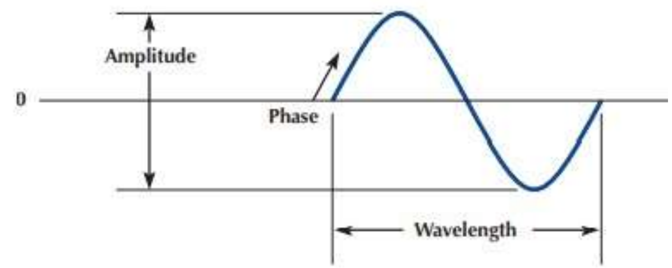
3.5 ANALOG TRANSMISSION OF DIGITAL DATA

- Telephone networks were originally built for human ***speech*** (audio, analog) rather than for data.
- They were designed to transmit the electrical representation of sound waves, rather than the binary data used by computers.
- There are many occasions when **data** needs to be transmitted over a voice communications network.
- Many people working at home still use a ***modem*** over their telephone line to connect to the Internet.
- The telephone system (commonly called ***POTS*** for plain old telephone service) enables voice communication between any two telephones within its network.
- How does the telephone work?
  - It converts the sound waves produced by the human voice at the sending end into electrical signals for the telephone network.
  - These electrical signals travel through the network until they reach the other telephone and are converted back into sound waves.

3.5 ANALOG TRANSMISSION OF DIGITAL DATA (contd).

- **Analog** transmission occurs when the signal sent over the transmission media **continuously varies** from one state to another in a wave-like pattern much like the human voice.
- Modems translate the digital binary data produced by computers into the analog signals required by voice transmission circuits. One modem is used by the transmitter to produce the analog signals and a second by the receiver to translate the analog signals back into digital signals.
- The sound waves transmitted through the voice circuit have three important characteristics (see Figure 3-14).

FIGURE 3-14
Sound wave



3.5 ANALOG TRANSMISSION OF DIGITAL DATA

- The first is the height of the wave, called amplitude.
  - **Amplitude** is measured in decibels (dB).
  - Our ears detect amplitude as the loudness or volume of sound.
  - Every sound wave has two parts, half above the zero amplitude point (i.e., positive) and half below (i.e., negative), and both halves are always the same height.
- The second characteristic is the length of the wave, usually expressed as the number of waves per second or frequency.
  - **Frequency** is expressed in hertz (Hz).
  - Our ears detect frequency as the pitch of the sound.
  - Frequency is the inverse of the length of the sound wave, so that a high frequency means that there are many short waves in a 1-second interval, whereas a low frequency means that there are fewer (but longer) waves in 1 second.
- The third characteristic is the **Phase**, which refers to the direction in which the wave begins.
    - Phase is measured in the degrees (°). The wave in Figure 3-14 starts up and to the right, which is defined as a 0° phase wave.
    - Waves can also start down and to the right (a 180° phase wave), and in virtually any other part of the sound wave.

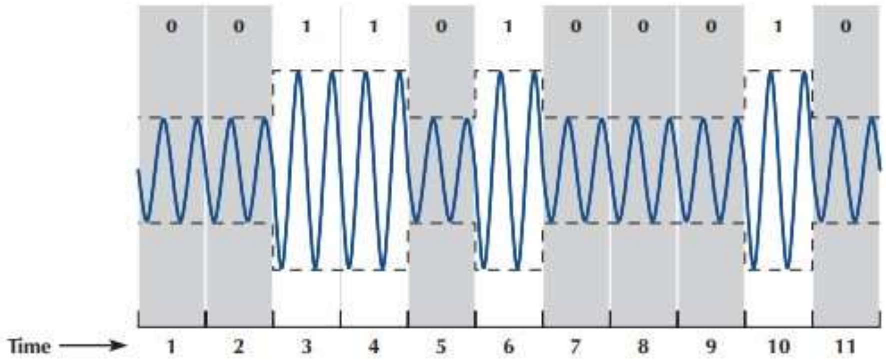
3.5.1 Modulation

- When we transmit data through telephone lines, we use the shape of the sound waves we transmit (in terms of amplitude, frequency, and phase) to represent different data values.
- We do this by transmitting a simple sound wave through the circuit (called the carrier wave) and then changing its shape differently to represent a 1 or a 0.
- Modulation is the technical term used to refer to these **"shape changes."**
- There are three fundamental modulation techniques:
  - amplitude modulation
  - frequency modulation, and
  - phase modulation.
- Once again, the sender and receiver have to agree on what symbols will be used **(what amplitude, frequency, and phase will represent a 1 and a 0)** and on the **symbol rate** (how many symbols will be sent per second)

Basic Modulation

- **ASK**
  - With amplitude modulation (AM) (also called amplitude shift keying [**ASK**]), the amplitude or height of the wave is changed.
  - One amplitude is the symbol defined to be 0, and another amplitude is the symbol defined to be a 1.
  - In the AM shown in Figure 3-15, the highest amplitude symbol (tallest wave) represents a binary 1 and the lowest amplitude symbol represents a binary 0.
  - In this case, when the sending device wants to transmit a 1, it would send a high-amplitude wave (i.e., a loud signal).
  - AM is more susceptible to (additive) noise (more errors) during transmission than is frequency modulation or phase modulation.

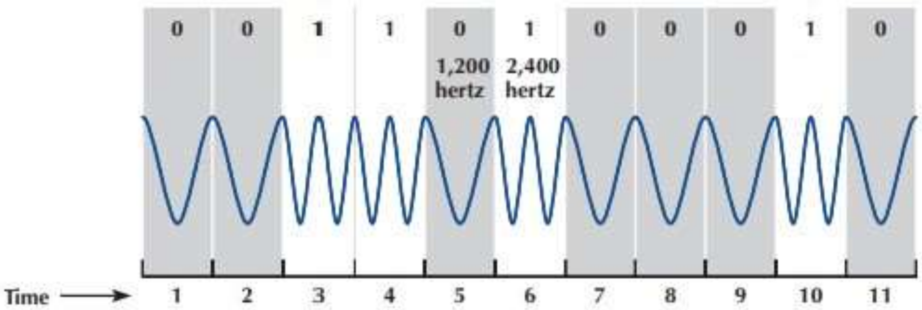
FIGURE 3-15
Amplitude modulation



Basic Modulation

- **FSK**
  - Frequency modulation (FM) (also called frequency shift keying [FSK]) is a modulation technique whereby each 0 or 1 is represented by a number of waves per second (i.e., a different frequency).
  - In this case, the amplitude does not vary.
  - One frequency (i.e., a certain number of waves per second) is the symbol defined to be a 1, and a different frequency (a different number of waves per second) is the symbol defined as a 0.

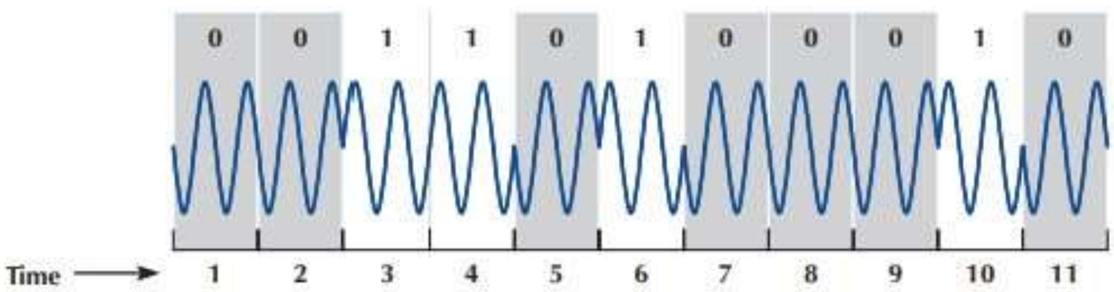
FIGURE 3-16
Frequency modulation



Basic Modulation

- PSK
  - Phase modulation (PM) (also called phase shift keying [PSK]) is the most difficult to understand.
  - Phase refers to the direction in which the wave begins.
  - Until now, the waves we have shown start by moving up and to the right (this is called a 0° phase wave).
  - Waves can also start down and to the right. This is called a phase of 180∘.
  - With phase modulation, one phase symbol is defined to be a 0, and the other phase symbol is defined to be a 1. Figure 3-17 shows the case where a phase of 0° symbol is defined to be a binary 0 and a phase of 180° symbol is defined to be a binary 1.

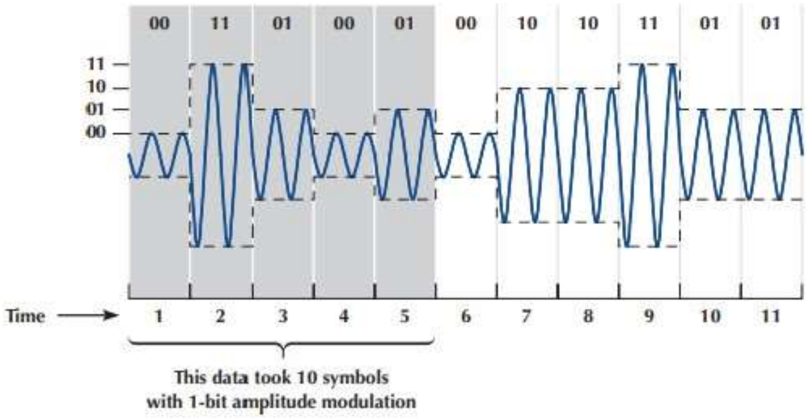
FIGURE 3-17
Phase modulation



Basic Modulation **(Sending Multiple Bits Simultaneously)**

- Each of the three basic modulation techniques (AM, FM, and PM) can be refined to send more than 1 bit at one time.
- For example, basic AM sends 1 bit per wave (or symbol) by defining two different amplitudes, one for a 1 and one for a 0.
- It is possible to send 2 bits on one wave or symbol by defining four **different** amplitudes.
- Figure 3-18 shows the case where the highest-amplitude wave is defined to be a symbol representing 2 bits, both 1s. The next highest amplitude is the symbol defined to mean first a 1 and then a 0, and so on.
- This technique could be further refined to send 3 bits at the same time by defining eight different symbols, each with different amplitude levels or 4 bits by defining 16 symbols.

FIGURE 3-18
Two-bit amplitude modulation



Basic Modulation (Sending Multiple Bits Simultaneously)

- This same approach can be used for FM and PM.
- Two bits could be sent on the same symbol by defining four different frequencies, one for 11, one for 10, and so on.
- Or by defining four phases (0∘, 90∘, 180∘, and 270∘).
- Three bits could be sent by defining symbols with eight frequencies or eight phases (0∘, 45∘, 90∘, 135∘, 180∘, 225∘, 270∘, and 315∘).
- These techniques are also subject to the same limitations as AM; as the number of different frequencies or phases becomes larger, it becomes difficult to differentiate among them.

Basic Modulation (Sending Multiple Bits Simultaneously)

- It is also possible to combine modulation techniques—that is, to use AM, FM, and PM techniques on the same circuit
  - For example, we could combine AM with four defined amplitudes (capable of sending 2 bits) with FM with four defined frequencies (capable of sending 2 bits) to enable us to send 4 bits on the same.
- One popular technique is quadrature amplitude modulation (QAM).
- QAM involves splitting the symbol into **eight** different phases (3 bits) and two different amplitudes (1 bit), for a total of 16 different possible values. Thus, one symbol in QAM can represent 4 bits
  - While 256-QAM sends 8 bits per symbol.
  - 64-QAM and 256-QAM are commonly used in digital TV services and cable modem Internet services.

Bit Rate versus Baud Rate versus Symbol Rate

- The terms bit rate (i.e., the number of bits per second transmitted) and baud rate are used incorrectly much of the time.
- They often are used interchangeably, but they are not the same.
- In reality, the network designer or network user is interested in bits per second because it is the bits that are assembled into characters, characters into words, and, thus, business information.
- A bit is a unit of information.
- A baud is a unit of signaling speed used to indicate the number of times per second the signal on the communication circuit changes.
- Because of the confusion over the term baud rate among the general public, ITU-T now recommends the term baud rate be replaced by the term **symbol rate**.
- The bit rate and the symbol rate (or baud rate) are the same only when 1 bit is sent on each symbol. For example, if we use AM with two amplitudes, we send 1 bit on one symbol.
    - Here, the bit rate equals the symbol rate.
- However, if we use QAM, we can send 4 bits on every symbol; the bit rate would be four times the symbol rate.
- If we used 64-QAM, the bit rate would be six times the symbol rate.
- Virtually all of today’s modems send multiple bits per symbol.

3.5.2 Capacity of a Circuit

- The data capacity of a circuit is the fastest rate at which you can send your data over the circuit in terms of the number of bits per second.
- The data rate (or bit rate) is calculated by multiplying the number of bits sent on each symbol by the maximum symbol rate.
- The number of bits per symbol depends on the modulation technique (e.g., QAM sends 4 bits per symbol).
- The maximum symbol rate in any circuit depends on the ***bandwidth available*** and the signal-to-noise ratio (the strength of the signal compared with the amount of noise in the circuit).
- The bandwidth is the difference between the highest and the lowest frequencies in a band or set of frequencies.
  - The range of human hearing is between 20 Hz and 14,000 Hz, so its bandwidth is 13,880 Hz.
- The maximum symbol rate for analog transmission is usually the same as the bandwidth as measured in hertz.
- If the circuit is very noisy, the maximum symbol rate may fall as low as 50% of the bandwidth.
- If the circuit has very little noise, it is possible to transmit at rates up to the bandwidth

3.5.2 Capacity of a Circuit (contd).

- Digital transmission symbol rates can reach as high as two times the bandwidth for techniques with only one voltage change per symbol (e.g., NRZ).
- For digital techniques with two voltage changes per symbol (e.g., RZ, Manchester), the maximum symbol rate is the same as the bandwidth.
- Standard telephone lines provide a bandwidth of 4,000 Hz.
  - Under perfect circumstances, the maximum symbol rate is therefore about 4,000 symbols per second.
  - If we used basic AM (1 bit per symbol), the maximum data rate would be 4,000 bits per second (bps).
  - If we used QAM (4 bits per symbol), the maximum data rate would be 4 bits per symbol × 4K symbols per second = 16 Kbps.
  - A circuit with a 10 MHz bandwidth using 64-QAM could provide up to 60 Mbps.

3.5.3 How Modems Transmit Data?

- The modem (an acronym for modulator/demodulator) takes the digital data from a computer in the form of electrical pulses and converts them into analog for transmission over an analog voice circuit.
- There are many different types of modems available today from **dial-up** modems to **cable modems**.
- For data to be transmitted between two computers using modems, both need to use the same type of modem.
- Fortunately, several standards exist for modems, and any modem that conforms to a standard can communicate with the other modem that conforms to the same standard.
- Data compression can increase the throughput of data over a communication link by literally **compressing** the data.
- V.44, the ISO standard for data compression, uses Lempel–Ziv encoding.
- As a message is transmitted, Lempel–Ziv encoding builds a dictionary of 2, 3, and 4 combinations in the message.
- Anytime the same character pattern reoccurs, the index to the dictionary entry is transmitted rather than sending the actual data.
- The reduction provided by V.44 compression depends on the actual data sent but usually averages about 6:1.

3.6 DIGITAL TRANSMISSION OF ANALOG DATA

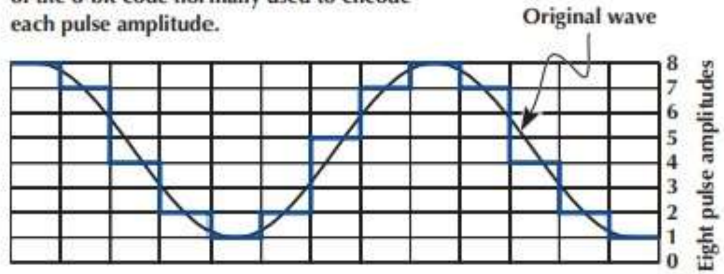
- In the same way that digital computer data can be sent over analog telephone networks using analog transmission, **analog voice data can be sent over digital networks using digital transmission**.
- This process is somewhat similar to the analog transmission of digital data.
- A pair of special devices called **codecs** (code/decode) is used in the same way that a pair of modems is used to translate the data to send across the circuit.
  - One codec is attached to the source of the signal (e.g., a telephone or the local loop at the end office) and translates the incoming analog voice signal into a digital signal for transmission across the digital circuit.
  - A second codec at the receiver’s end translates the digital data back into analog data

3.6.1 Translating from Analog to Digital

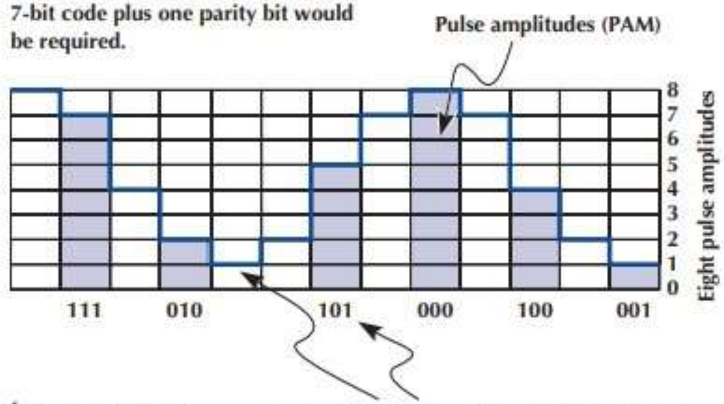
- Analog voice data must first be translated into a series of binary digits before they can be transmitted over a digital circuit.
- This is done by sampling the amplitude of the sound wave at regular intervals and translating it into a binary number.
- Figure 3-19 shows an example where eight different amplitude levels are used (i.e., each amplitude level is represented by 3 bits).
- The top diagram shows the original signal, and the bottom diagram shows the digitized signal.
- A quick glance will show that the digitized signal is only a rough approximation of the original signal.
- The original signal had a smooth flow, but the digitized signal has jagged “steps.”
- The difference between the two signals is called ***quantizing error***.
- Voice transmissions using digitized signals that have a great deal of quantizing error ***sound metallic or machine like*** to the ear.

FIGURE 3-19
Pulse amplitude modulation (PAM)

The signal (original wave) is quantized into 128 pulse amplitudes (PAM). In this example we have used only eight pulse amplitudes for simplicity. These eight amplitudes can be depicted by using only a 3-bit code instead of the 8-bit code normally used to encode each pulse amplitude.



After quantizing, samples are taken at specific points to produce amplitude modulated pulses. These pulses are then coded. Because we used eight pulse levels, we only need three binary positions to code each pulse.[1] If we had used 128 pulse amplitudes, then a 7-bit code plus one parity bit would be required.



[1]001 = PAM level 1
010 = PAM level 2
011 = PAM level 3
100 = PAM level 4
101 = PAM level 5
110 = PAM level 6
111 = PAM level 7
000 = PAM level 8

For digitizing a voice signal, 8,000 samples per second are taken. These 8,000 samples are then transmitted as a serial stream of 0s and 1s. In our case 8,000 samples times 3 bits per sample would require a 24,000 bps transmission rate. In reality, 8 bits per sample times 8,000 samples requires a 64,000 bps transmission rate.

3.6.1 Translating from Analog to Digital (contd)

- Reducing quantizing error and improving the quality of the digitized signal involves cost. Two ways:
  - The **first** is to increase the number of amplitude levels. This minimizes the difference between the levels (the “height” of the “steps”) and results in a smoother signal.
  - In Figure 3-19, we could define 16 amplitude levels instead of eight levels. This would require 4 bits (rather than the current 3 bits) to represent the amplitude, thus increasing the amount of data needed to transmit the digitized signal.
  - No amount of levels or bits will ever result in perfect-quality sound reproduction, but in general, 7 bits (27 = 128 levels) reproduce human speech adequately.
  - Music, on the other hand, typically uses 16 bits (216 = 65,536 levels).

3.6.1 Translating from Analog to Digital (contd)

- The **second** method is to sample more frequently. This will reduce the “length” of each “step,” also resulting in a smoother signal.
  - To obtain a reasonable-quality voice signal, one must sample at least twice the highest possible frequency in the analog signal.
    - You will recall that the highest frequency transmitted in telephone circuits is 4,000 Hz. Thus, the methods used to digitize telephone voice transmissions must sample the input voice signal at a minimum of 8,000 times per second.
  - Sampling more frequently than this (called oversampling) will improve signal quality. RealNetworks.com, which produces Real Audio and other Web-based tools, sets its products to sample at 48,000 times per second to provide higher quality.
  - The iPod and most CDs sample at 44,100 times per second and use 16 bits per sample to produce almost error-free music.
  - Some other MP3 players sample less frequently and use fewer bits per sample to produce smaller transmissions, but the sound quality may suffer

3.6.2 How Telephones Transmit Voice Data?

- When you make a telephone call, the telephone converts your analog voice data into a simple analog signal and sends it down the circuit from your home to the telephone company's network.
- This process is almost unchanged from the one used by Bell when he invented the telephone in 1876.
- With the invention of digital transmission, the common carriers (i.e., telephone companies) began converting their voice networks to use digital transmission.
- Today, all of the common carrier networks use digital transmission, except in the local loop (sometimes called the last mile), the wires that run from your home or business to the telephone switch that connects your local loop to the telephone network.
- This switch contains a **codec** that converts the analog signal from your phone into a digital signal.
- This digital signal is then sent through the telephone network until it hits the switch for the local loop for the person you are calling.
  - This switch uses its codec to convert the digital signal used inside the phone network back into the analog signal needed by that person's local loop and telephone (Figure 3-20)

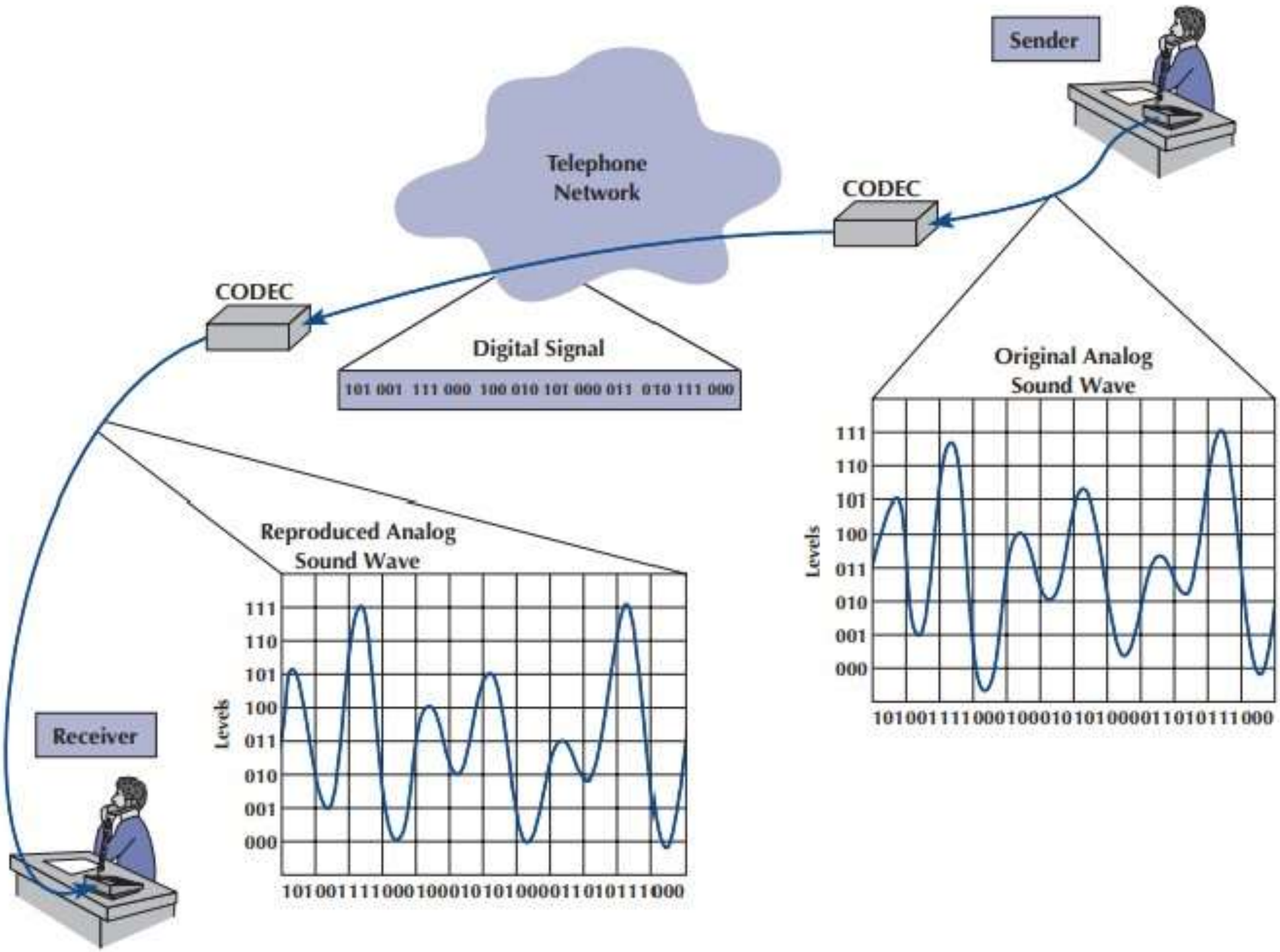


FIGURE 3-20 Pulse amplitude modulation (PAM)

3.6.2 How Telephones Transmit Voice Data? (contd).

- There are many different combinations of sampling frequencies and numbers of bits per sample that could be used.
- For example:
  - You could sample 4,000 times per second using 128 amplitude levels (i.e., 7 bits) or,
  - Sample at 16,000 times per second using 256 levels (i.e., 8 bits).
- The North American telephone network uses pulse code modulation (PCM).
- With PCM, the input voice signal is sampled 8,000 times per second. Each time the input voice signal is sampled, 8 bits are generated.
- Therefore, the **transmission speed on the digital circuit must be 64,000 bps** (8 bits per sample × 8,000 samples per second) to transmit a voice signal when it is in digital form.
- Thus, the North American telephone network is built using millions of 64 Kbps digital circuits that connect via codecs to the millions of miles of analog **local loop circuits** in the users' residences and businesses.

3.6.3 How Instant Messenger Transmits Voice Data? (contd).

- A 64 Kbps digital circuit provides very good quality for transmitting voice data, but the problem is that it requires a lot of capacity.
- Adaptive Differential PCM (ADPCM) is the alternative used by IM and other applications that provide voice services over lower-speed digital circuits.
- ADPCM works in much the same way as PCM.
  - It samples incoming voice signals 8,000 times per second and calculates the same 8-bit amplitude value as PCM.
  - However, instead of transmitting the 8-bit value, it transmits the difference between the 8-bit value in the last interval and the current (i.e., how the amplitude has changed from one time period to another).
  - Because analog voice signals change slowly, these changes can be adequately represented by using only **4** bits.
  - This means that ADPCM can be used on digital circuits that provide only 32 Kbps (4 bits per sample × 8,000 samples per second = 32,000 bps).
  - Several versions of ADPCM have been developed and standardized by the ITU-T.
  - There are versions designed for 8 Kbps circuits (which send 1 bit 8,000 times per second) and 16 Kbps circuits (which send 2 bits 8,000 times per second, poor quality), as well as the original 32 Kbps (good quality) version.

3.6.4 Voice over Internet Protocol (VoIP)

- Voice over Internet Protocol (VoIP, pronounced “voyp”) is commonly used to transmit phone conversations over digital networks.
- VoIP is a relatively new standard that uses digital telephones with ***built-in codecs*** to convert analog voice data into digital data (see Figure 3-21).
- Because the codec is in, the telephone transmits digital data and therefore can be connected directly to a LAN in the same way as a computer.
- Because VoIP phones operate on the same networks as computers, we can **reduce the amount of wiring needed**; with VoIP, we need to operate and maintain only one network throughout our offices, rather than two separate networks—one for voice and one for data.
- However, this also means that data networks with VoIP phones must be designed to operate in emergencies (to enable 911 calls) even when the power fails; they must have uninterruptable power supplies (UPS) for all network circuits.
- One commonly used VoIP standard is G.722 wideband audio, which is a version of ADPCM that operates at 64 Kbps. It samples 8,000 times per second and produces 8 bits per sample.
- Because VoIP phones are digital, they can also contain additional capabilities.
  - (Can download and install small software applications so that they can function in many ways like computers).

3.7 IMPLICATIONS FOR MANAGEMENT

- In the past, networks used to be designed so that the physical cables transported data in the same form in which the data were created:
  - Analog voice data generated by telephones used to be carried by analog transmission cables and
  - Digital computer data used to be carried by digital transmission cables.
- In most cases, **the cheapest and highest-quality media are digital.**
- Thus, the convergence of voice and video and data at the physical layers is being driven primarily by business reasons: Digital is better.
- The change in physical layers also has implications for organizational structure.
- **Voice data used to be managed separately from computer data because they use different types of networks.**
- **Today, more organizations are placing the management of voice telecommunications into their information systems organizations.**
- **This also has implications for the telecommunications industry (OTT).**